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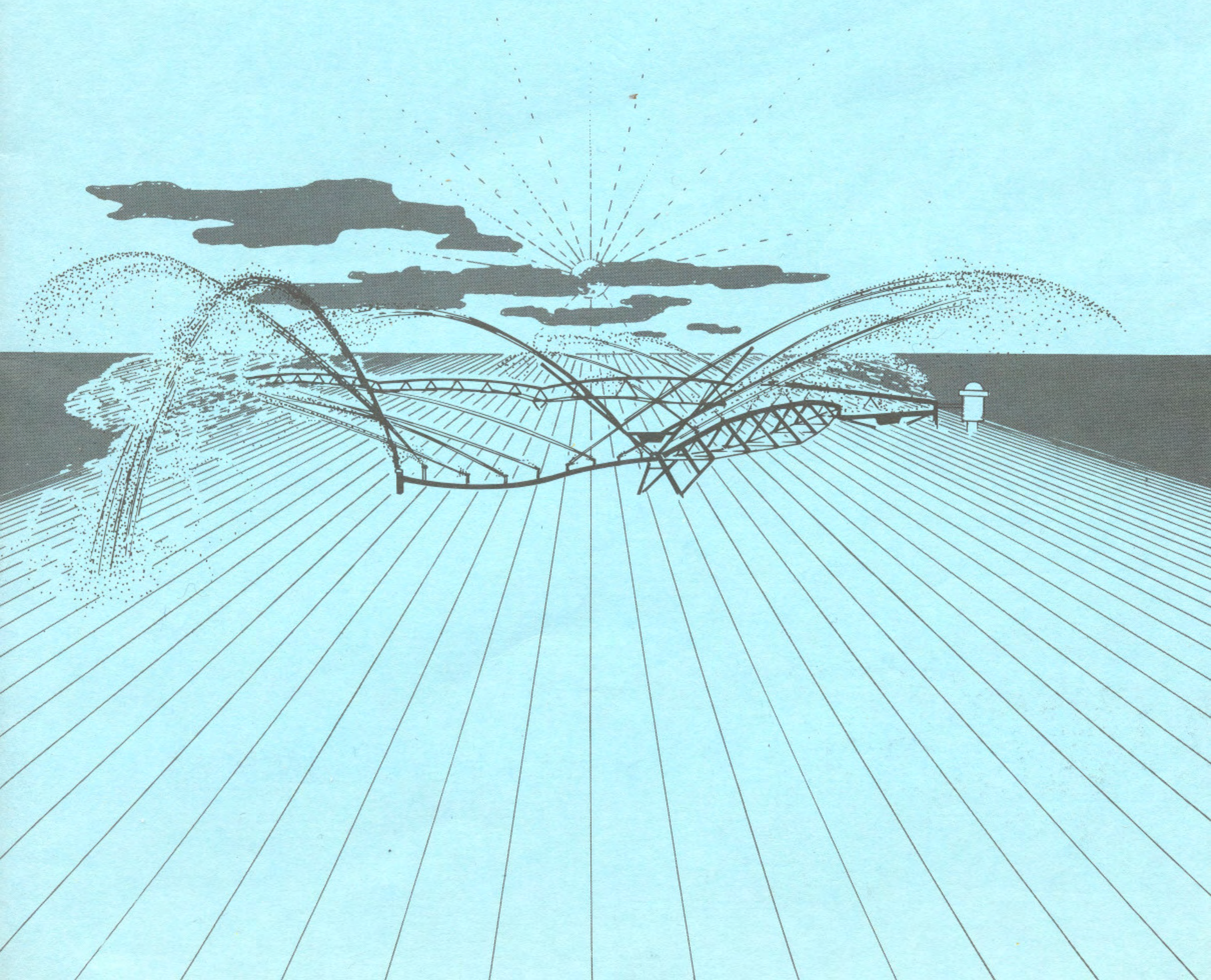
APPRAISAL OF THE GROUNDWATER RESOURCES OF BARTON, VERNON, AND BATES COUNTIES, MISSOURI

by

Michael J. Kleeschulte, Thomas O. Mesko, and James E. Vandike



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APPRAISAL OF THE GROUNDWATER RESOURCES OF BARTON, VERNON, AND BATES COUNTIES, MISSOURI

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CONVERSION FACTORS

For readers who prefer to use metric units, conversion factors for terms used in this report are listed below:

Multiply	by	To obtain
inch (in.)	25.40	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
foot per second (ft/sec)	0.3048	meter per second
foot per mile (ft/mi)	0.1984	meter per kilometer
foot squared per day (ft^2/day)	0.0929	meter squared per day
gallon per minute (gpm)	5.4510	cubic meter per day
million gallon per day (mgd)	0.4381	cubic meter per second
gallon per minute per foot (gpm/ft)	0.207	liter per second per meter
gallon per day per foot (gpd/ft)	0.0124	meter squared per day
micromho per centimeter (μmho/cm) at 25° Celsius	1.000	microsiemens per centimeter at 25° Celsius

Temperature in degrees Fahrenheit ($^{\circ}$F) can be converted to degrees Celsius ($^{\circ}$C) as follows: $^{\circ}C = 5/9\ (^{\circ}F\text{-}32)$.

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level. NGVD of 1929 is referred to as sea level in this report.

ABSTRACT

Groundwater resources in Barton, Vernon, and Bates Counties are limited by aquifer characteristics and restricted by water quality. The Pennsylvanian aquifer, consisting of cyclic deposits of clastic and carbonate rocks, yields approximately 1 to 40 gallons per minute (gpm) to domestic wells in the northern and western parts of the study area. The Pennsylvanian strata, however, generally functions as a leaky confining bed for the underlying Mississippian aquifer, which comprises carbonate units with minor layers of fine clastics and generally yields 15 to 20 gpm to domestic and stock wells in much of the southern and eastern parts of the study area. Kinderhookian strata, consisting of fine clastics and carbonate rocks, form a relatively impermeable, or confining, layer near the base of the Mississippian System. The Cambrian-Ordovician aquifer, consisting of a sequence of thick carbonate rocks and thin sandstone layers, yields as much as 1200 gpm to municipal, industrial, and irrigation wells. Although the permeable water-producing zones are separated by less-permeable zones, hydraulic connection exists throughout the sequence.

The Pennsylvanian aquifer principally is recharged by precipitation. The water level generally is from 15 to 40 feet (ft) below land surface, and water movement is toward stream and river valleys. Because the Pennsylvanian aquifer is a leaky confining layer, water probably moves through it and recharges the underlying Mississippian aquifer. Depending on depth and location, lithologic controls allow the water to be under both confined and unconfined conditions in the Mississippian aquifer, which is mostly recharged by precipitation in the region east of the study area, where Mississippian strata crop out. Water movement in the system is to the north and west. A comparison of the historical and current water-level measurements shows that throughout a long time, discharge is balanced by recharge in the Pennsylvanian and Mississippian aquifers. Water levels in the two have not been significantly affected during the past 40 years, except for local drawdowns in the Mississippian aquifer, in places where water is intensively pumped. The Cambrian-Ordovician aquifer is mostly recharged by precipitation on the Salem Plateau, where this system crops out. Water movement through this aquifer is westward and northwestward. There has been concern that increasing withdrawals from the Cambrian-Ordovician aquifer in Barton, Vernon, and Bates Counties would cause declines in water levels and result in encroachment of saline water (more than 1000 milligrams per liter (mg/l) of dissolved solids) into freshwater areas.

A transition zone diagonally crossing the three counties separates freshwater in the southeast from saline water in the northwest. Northwest of the zone, water salinity is significantly higher than in the southeast. The potentiometric surface of the Cambrian-Ordovician aquifer has declined approximately 80 ft in parts of the study area since the early 1900's. This rate of decline has accelerated due to increased withdrawals for industrial use and crop irrigation during the past 10 years and for public water supply during the past 20 years. Despite this increase in groundwater withdrawals during recent years, the location of the freshwater-saline water transition zone has not substantially changed, although minor fluctuations have occurred along the boundary zone. Water from public-supply wells in Barton and Vernon Counties, however, has changed from a calcium magnesium bicarbonate-type to a sodium chloride-type, with no appreciable change in dissolved-solids concentrations.

INTRODUCTION

Approximately one-third of Missouri is underlain by aquifers that contain saline water. The freshwater-saline water transition zone in the Cambrian-Ordovician aquifer generally coincides with the limit of Pennsylvanian rocks in northern and western Missouri. Barton, Vernon, and Bates Counties are in this transition zone in southwestern Missouri. There are increasing demands for water in these counties, from energy-related industries, for supplemental irrigation of crops, and for public water supplies. There is concern that additional large withdrawals will lower the potentiometric surface and possibly allow encroachment of saline water into freshwater areas.

Purpose and Scope

This report describes the occurrence, distribution, recharge, movement, discharge, chemical quality, and use of groundwater in Barton, Vernon, and Bates Counties. An appraisal of area groundwater resources, past and present, is necessary for their future optimum development.

Description of the Study Area

The three-county study area, comprising 2273 square miles (mi^2), is in southwestern Missouri adjoining the Kansas border (fig. 1). The northwest boundary of Bates County is at latitude 38°28'39", longitude 94°36'46"; the southeast boundary of Barton County is at latitude 37°20'57", longitude 94°04'55". The economy of the region is primarily agricultural. The most important crops are corn, wheat, and soybeans; the principal livestock raised are cattle and hogs. Additional contributions to the economy come from small industries, military installations, mining, and institutions in and near the large communities. The soil texture generally is silty to fine sandy loam, with an increasing clay content (claypan) at depth. The largest cities in the study area are Lamar (population 3760), in Barton County; Nevada (population 9736), in Vernon County; and Butler (population 3984) in Bates County.

Previous Investigations

The major emphasis of the earliest groundwater studies in southwestern Missouri concerned regional hydrology and water quality. The existence of lead and zinc deposits in the Tri-State Mining District, the large withdrawals of groundwater associated with mining operations, and the confined conditions of the lower Paleozoic aquifers in the area were catalysts for these studies.

The earliest reports about the area were published by the U.S. Geological Survey. Shepard (1907) described several flowing wells in Barton and Vernon Counties that were producing water from the Mississippian and Cambrian-Ordovician aquifers. Shepard also included some water-quality data and logs for these wells. Siebenthal (1915) discussed the genesis of lead and zinc deposits in the Joplin area of southwest Missouri and the effects of artesian conditions contributing to the concentrations of these ores. He also noted several flowing wells in southwest Missouri. Greene and Pond (1926) reported on the geography and geology of Vernon County. They described several flowing wells, giving their locations, the formations penetrated, and analyses of water from them.

Several groundwater resources studies have been made in the study area and adjacent counties. Abernathy (1941) evaluated the groundwater resources of

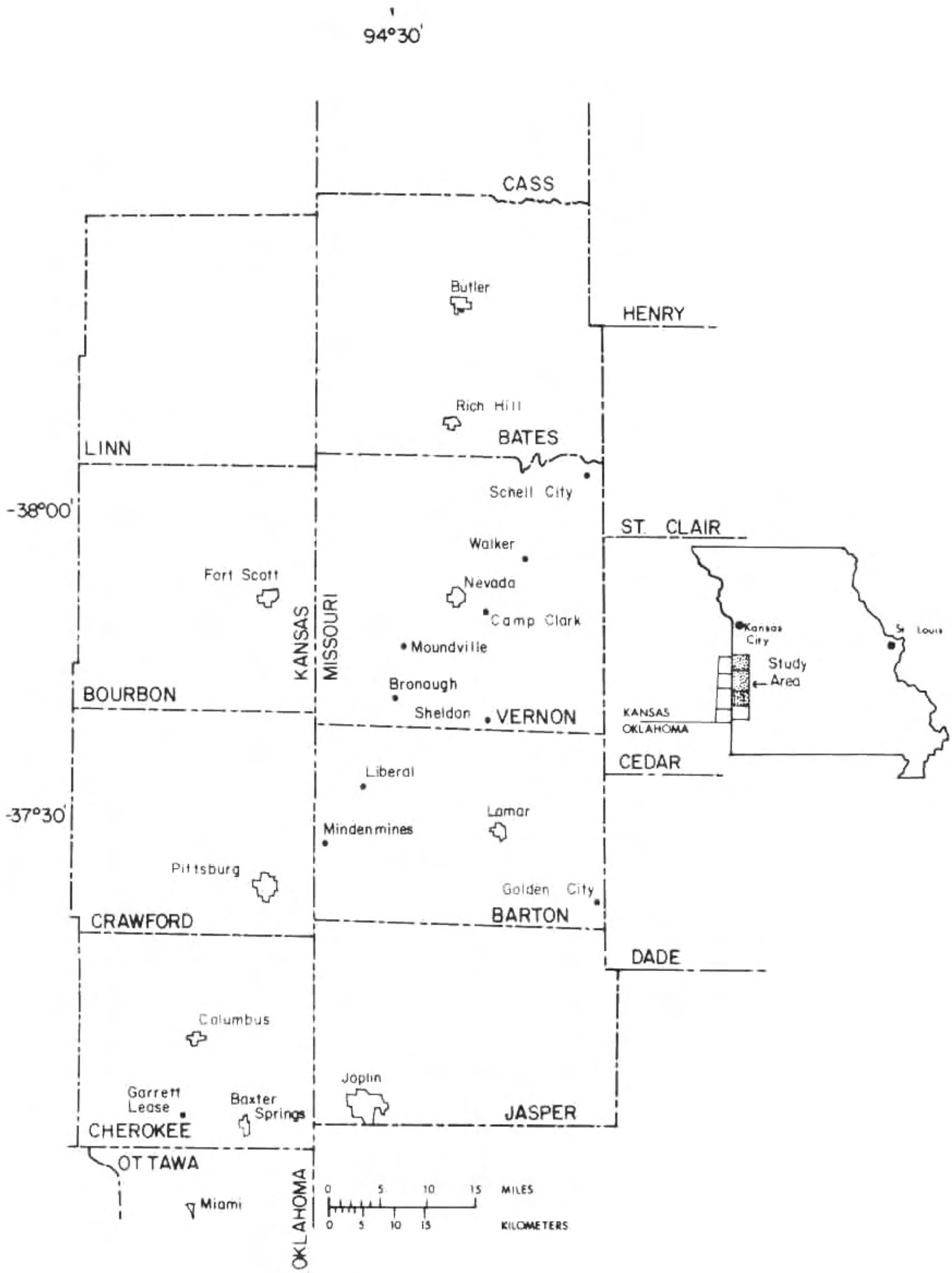


Figure 1 — Location of study area and adjacent counties.

a four-county area in Kansas, described expected yields from wells completed in the Mississippian and in the Cambrian-Ordovician aquifers, and indicated that subsurface geologic structure contributed to increased yields. Seevers (1969) described the groundwater resources and geology of Linn County, Kansas, due west of Bates County; and Gentile (1976) reported on the geology and water resources of Bates County. Both Seevers and Gentile stated that the yield of groundwater from the Pennsylvanian rocks rarely exceeds 1 gpm, and that groundwater below a depth of 100 ft generally is excessively mineralized and unsuitable for use. Yields of approximately 10 gpm can be obtained from Ordovician strata. Gentile also described the Pennsylvanian stratigraphy in Bates County in detail.

Williams (1948) sampled three deep saltwater-contaminated municipal wells in Crawford County, Kansas, and concluded that if wells are not properly grouted during construction, saline water associated with shale of the Cherokee Formation will corrode casings, a process that would eventually allow saline water to enter the wells.

Groundwater studies were made by Reed and others (1955) and Gann and others (1974). Reed and others studied the aquifers used in the mining district of Ottawa County, Oklahoma. They gave useful estimates of groundwater withdrawal attributed to the mining operations. Gann and others studied the water resources of west-central Missouri. Their hydrologic investigation reported surface-water availability and quality, groundwater availability and quality, aquifer characteristics, and water-use data on a regional scale.

Stramel (1957) determined the hydrologic properties of the Ordovician rocks by using results of aquifer tests on eight municipal wells in Pittsburg, Kansas. Because the calculated water-level decline was much less than the actual decline, he concluded that the Cambrian-Ordovician aquifer and the overlying Mississippian aquifer were connected. He also concluded that the actual decline of water levels in the Cambrian-Ordovician aquifer was due in part to extensive pumping of the Mississippian aquifer for mine dewatering and to ". . . the relatively small areal extent of the very permeable part of the (Ordovician) aquifer . . .," which is in the Pittsburg area.

Melton (1976) reported on the regional geohydrology of the Roubidoux Formation and Gasconade Dolomite in Arkansas and Missouri. He concluded that large yields of water can be obtained from wells that penetrate major and minor lineaments and fractures. Groundwater from wells completed in these formations are of the calcium magnesium bicarbonate-type, and dissolved-solids concentrations are small along groundwater divides and large in groundwater troughs.

In the study area Darr (1978) confirmed the presence of a salinity gradient that decreases southeastward. From samples collected in 1966 and 1976, he indicated salinity concentrations gradually were increasing, and that saltwater was encroaching in parts of the freshwater area of Vernon and Bates Counties. Darr also studied the equilibrium states between various dissolved minerals and the groundwater.

While modeling the Center Creek basin in southwestern Missouri, Harvey and Emmett (1980) assigned a vertical hydraulic conductivity of 5.0×10^{-10} foot per second (ft/sec) to the confining Northview Shale and a storage coefficient of 1.0×10^{-4} for nonbrecciated areas and 1.0×10^{-3} for the brecciated area of the Mississippian aquifer.

Harvey (1980) reported on the groundwater conditions in the Springfield-Salem Plateaus of southern Missouri and the occurrence and effects of sinkholes and losing streams on groundwater recharge.

Frick (1980) studied the distribution, occurrence, movement, and quality of water in Mississippian and Ordovician rocks in southwest Missouri and southeast Kansas. Frick concluded structural features affect aquifer flow characteristics and control movement of brackish water. He also concluded that if groundwater withdrawals continue to increase, the potentiometric surface will decline, a factor that may result in the eastward movement of brackish water, perhaps at a greater rate than now exists.

Macfarlane and others (1980) reported on the hydrogeology and chemical quality of water in the lower Paleozoic aquifers in southeast Kansas and adjoining states. They concluded that concentrations of chloride and dissolved solids increase with depth in the Cambrian-Ordovician aquifer. Groundwater chemistry west of the freshwater-saline transition zone reflects the presence of a reducing environment. Only a few groundwater chemical-quality changes were documented in this study. Specific conductances decreased during a 24-hour aquifer test at Baxter Springs, Kansas. Periodic fluctuations in bicarbonate concentrations were present in water samples from Mindenmines, Missouri, and long-term increases in chloride concentrations were recorded during monitoring of the Crawford County rural water district in Kansas.

Well-Numbering System

In this report, location of wells and test holes follows the General Land Office coordinate system. According to this system (fig. 2) the first three sets of numbers of a well number designate

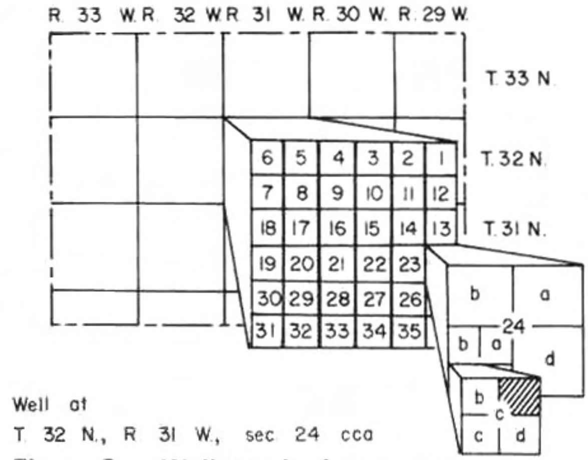


Figure 2 — Well-numbering system.

township, range, and section, respectively. The letters that follow indicate quarter section, quarter-quarter section, and quarter-quarter-quarter section. The quarter sections are represented by letters a, b, c, and d, in counterclockwise order, starting in the northeast quadrant. Two or more wells or test holes in the same division are numbered serially in the order in which they were inventoried.

Acknowledgments

The authors acknowledge the help and support of all the irrigation-well, test-hole, and domestic-well owners, and the officials of municipal water supplies and water-supply districts, for allowing access to their wells for sampling and making water-level measurements.

The authors especially acknowledge the help of Jerry Gibbs, City Engineer, Nevada, Missouri, for helping locate the old Harry Moore flowing well near Nevada; and Ralph Williston for providing water-use estimates for a manufacturing plant in Lamar, Missouri. Carolyn Taffner, City Clerk, Lamar, Missouri, and J.A. Roberts, Superintendent, city of Lamar, helped by describing the development and operating procedures of their municipal water supply.

STRATIGRAPHY

The consolidated stratigraphic section in Barton, Vernon, and Bates Counties consists of Middle Pennsylvanian to Late Cambrian sedimentary rocks (table 1). Unconsolidated Quaternary alluvium occurs along major streams in the area, but due to limited areal extent, it is not considered in this study. The consolidated strata rest unconformably on Precambrian granite and metasedimentary rocks. The total thickness of the sedimentary section in the three-county area ranges from a minimum of approximately 1250 ft in western Vernon County to a maximum of 2200 ft in northwestern Bates County. Limestone and dolomite are the principal rock types, but the stratigraphic section also includes chert, shale, sandstone, and coal beds. The systems included are Pennsylvanian, Mississippian, Devonian, Ordovician, and Cambrian.

Pennsylvanian System

The Pennsylvanian System is represented by the Kansas City and Pleasanton Groups of the Missourian Series and the Marmaton and Cherokee Groups of the Desmoinesian Series. Pennsylvanian strata are absent in eastern Barton and Vernon Counties and reach a maximum thickness of 720 ft in northwestern Bates County, where the Kansas City and Pleasanton Groups of the Missourian Series are present, though of limited areal extent. Strata of the Marmaton and Cherokee Groups crop out throughout much of the study area. In western Barton, Vernon, and Bates Counties, the interbedded sandstone is saturated with heavy oil.

Mississippian System

Mississippian rocks lie unconformably on Ordovician strata and crop out locally in eastern Barton and Vernon Counties. The Mississippian System comprises the Meramecian, Osagean, and Kinderhookian Series. The Mississippian section is mostly limestone, locally grading downward to dolomite, but it also includes some chert and shale layers. The total section typically is 350 to 400 ft thick in the study area, but only about 250 ft thick on the Golden City-Miller anticline, in Barton County.

In the study area, the Meramecian Series, which is considered to lie conformably on the Osagean Series, is represented only by the Warsaw Formation, which attains a maximum thickness of 140 ft in Barton County and a minimum of 25 ft in Bates County.

The Osagean Series, which lies unconformably on the Chouteau Group, is typically dense, cherty limestone grading downward to silty dolomite and comprises the Keokuk and Burlington Limestones, Elsey Formation, Reeds Springs Formation, and the Pierson Formation. The section generally is more than 220 ft thick in the study area; it reaches a maximum of 290 ft in southern Barton County and a minimum of 170 ft in southern Bates County.

In southwest Missouri, the Kinderhookian Series includes, in descending order, the Northview Formation, Sedalia Formation, and the Compton Formation, a sequence also typical of the Chouteau Group throughout much of central Missouri. The Northview Formation is the principal confining unit between the Mississippian limestones and the Cambrian-Ordovician dolomites. In southern Vernon and northern Barton Counties, the Northview thickens, as the Sedalia thins, to approximately 80 ft. Northward, the thickness of the Northview decreases rapidly and may be less than 10 ft or locally absent in Bates and northern Vernon Counties. In places in the study area, a formation lithologically similar

SYSTEM	SERIES	STRATIGRAPHIC UNIT	MAP SYMBOL	THICKNESS IN FEET	PHYSICAL CHARACTERISTICS	DEPTH TO FORMATION TOP IN FEET		WATER-BEARING CHARACTERISTICS
QUATERNARY	HOLOCENE	Alluvium						
PENNSYLVANIAN	MISSOURIAN	Kansas City Group Undifferentiated	₱k	0-80	Thick, alternating beds of shale, clay, and sand.	Outcrop	Pennsylvanian aquifer	Primarily a confining layer; Moderate quantities of water obtained from moderately thick sands and fractured limestones. Yields vary from less than 1 gallon per minute to locally as much as 40 gallons per minute. Domestic and stock use.
		Pleasanton Group Undifferentiated	₱p	0-160	Sandstone, shale, and limestone layers; dominantly clastic.	Outcrop to 55		
	DESMOINESIAN	Marmaton Group Undifferentiated	₱m	0-80	Interbedded cyclic limestone, sandstone, shale, with some coal beds.	Outcrop to 215		
		Cherokee Group Undifferentiated	₱c	0-400	Interbedded cyclic limestone, sandstone, shale, with some coal beds.	Outcrop to 300		
MISSISSIPPIAN	MERAMECIAN	Warsaw Formation	Mw	25-140	Dense limestone with chert and locally shale.	Outcrop to 700	Mississippian aquifer	Yields little water.
	OSAGEAN	Keokuk and Burlington Limestones	Mo	Where Differentiated: 80-230	Dense cherty limestone; lower half locally dolomitic.	Outcrop to 725		Average yield 15-20 gallons per minute; locally as much as 60 gallons per minute near brecciated areas and solution-enlarged openings. Domestic and stock use.
		Elsey Formation		0-75	Fine-grained, very cherty limestone.			
		Reeds Spring Formation		0-120	Dark, very cherty, argillaceous limestone.			
		Pierson Formation		0-60	Cherty, dolomitic limestone grading down to silty dolomite.			Yields very small quantities of water.
	KINDERHOOKIAN	Northview Formation	Mn	0-80	Shale or shaly limestone; locally silty, commonly green.	200 to 900		Confining bed.
		Sedalia and Compton Formations Undifferentiated	Mx	0 to 110	Finely to medium-crystalline limestone; locally may be dolomitic	90 to 900		Yields small quantities of water. Confining bed.
DEVONIAN	UPPER	Chattanooga Shale	Dc	0-10	Black carbonaceous shale.	480 to 630		Confining bed.
ORDOVICIAN	LOWER	Cotter and Jefferson City Dolomites	Ocj	105 to 320	Dolomite with thin shale and sandstone interbeds. Frequently dolomite is silty or contains chert.	230 to 1,000	Cambrian-Ordovician aquifer	Yields small quantities of water.
		Roubidoux Formation	Or	110 to 190	Cherty, sandy dolomite and sandstone beds.	470 to 1,225		Upper 50 to 75 feet yields 50 to 75 gallons per minute. Well completely penetrating Roubidoux yield 350 to 1,000 gallons per minute.
		Gasconade Dolomite	Og	220 to 300	Chety dolomite with sandy dolomite unit (Gunter Sandstone Member) at base.	630 to 1,350		Upper Gasconade yields 250 to 600 gallons per minute. Lower Gasconade yields 350 to 1,000 gallons per minute.
CAMBRIAN	UPPER	Eminence and Potosi Dolomites	Єep	140 to 260	Coarsely crystalline gray dolomite grading down to a medium-crystalline dolomite.	910 to 1,575		Yields 500 to 1,200 gallons per minute.
		Derby-Doerun Dolomite and Davis Formations Undifferentiated	Єd	0 to 255	Upper half: Dolomite with oolites and chert grading down to dolomite with shale; sand, and glauconite. Lower half: Shale, siltstone, sandstone, dolomite, and limestone.	1,170 to 1,725		Yields small quantities of water. May be confining bed.
		Reagan Sandstone	Єr	18 to 220	Quartzose sandstone containg silt and shale; arkosic at base.	1,225 to 1,950		Yields vary considerably. Formation thins over Precambrian highs.
PRECAMBRIAN					Metasedimentary rocks, granite, gneissic granites and rhyolites.	1,255 to 2,100		Generally does not yield water

TABLE 1

Generalized section of geologic formations

to the Sedalia is present above the Northview shale, instead of below it. It is believed the Sedalia also may be present above the Northview, due to a change in depositional environment that caused interfingering of beds (J.R. Palmer, Missouri Division of Geology and Land Survey, oral commun., 1982). Such interfingering between the Sedalia and the Compton makes them indistinguishable.

Devonian System

The Chattanooga Shale is intermittently present throughout the area but is rarely identified on well logs; where present, it is generally only a few feet thick. As a continuous formation, the Chattanooga Shale pinches out approximately 10 miles (mi) south of Joplin (U.S. Geological Survey and Missouri Geological Survey and Water Resources, 1967).

Ordovician System

In southwest Missouri, Lower Ordovician strata lie unconformably on Upper Cambrian rocks. In descending order, the Lower Ordovician formations are the Cotter Dolomite, Jefferson City Dolomite, Roubidoux Formation, and the Gasconade Dolomite, a sequence characterized by fine- to medium-crystalline, silty, cherty dolomites, with limestone, shale, and sand lenses. Scattered oolite horizons are common in each formation. The Lower Ordovician rocks are more uniform in thickness than the Upper Cambrian Series; they reach a maximum of 620 ft in central Barton County and a minimum of 500 ft in central Vernon County.

The Cotter and Jefferson City Dolomites are treated as a combined unit because of lithologic similarities and difficulty in differentiating them. The Cotter begins to pinch out in eastern Vernon County. The Roubidoux Formation lies unconformably on the Gasconade and conformably under the Cotter and Jefferson City Dolomites. The Gasconade Dolomite usually can be divided into three units: the upper is dolomite with some chert, the middle is characterized by cherty dolomite, and the basal unit is a reliable marker bed consisting of a persistent sandy dolomite, the Gunter Sandstone Member.

Cambrian System

The Upper Cambrian formations, which lie unconformably on Precambrian rocks, are the Eminence Dolomite, Potosi Dolomite, Derby-Doerun Dolomite, Davis Formation, and Reagan Sandstone. There are significant differences in attitude and thickness of individual formations between strata overlying the Precambrian hills and ridges and those filling the valleys.

The Eminence lies conformably on the Potosi Dolomite and the Potosi, on the Derby-Doerun. Because of similarities in lithology and other physical characteristics, the contact between the Eminence and the Potosi is obscure (Koenig, 1961); hence, the two are undifferentiated in table 1. The thickness of both dolomites decreases in western Vernon County, but a thickness of about 260 ft generally is present throughout the rest of the study area.

The Derby-Doerun Dolomite marks a general change in character of the Upper Cambrian sedimentary rocks. The lower half of the formation marks the end of a Cambrian sedimentary sequence having abundant clastics; the upper half, the beginning of a shallow-water, carbonate-platform depositional environment. The Davis Formation, which lies conformably on the Reagan Sandstone, normally contains more shale than the units above and below it. The contact between the

Derby-Doerun and the Davis is not well-defined everywhere, because the beds intertongue in places and the shale and silt contents of both formations are similar near the contact. Although the Derby-Doerun Dolomite and Davis Formation vary widely in thickness, their combined thickness, where they are present, is typically 135 to 200 ft.

The Reagan Sandstone, as now recognized in Missouri, is present throughout the study area (Bohm and Anderson, 1981). That identified as Lamotte Sandstone on several older well logs is now believed to be Reagan Sandstone. Although the Reagan is not comparable to the clean, monomineralic quartz sandstone of the bulk of the Lamotte, the two formations are related; they are both near-shore clastic deposits laid down by a transgressing Cambrian sea. According to Kurtz and others (1975, p. 9) ". . . the Reagan is a predominantly time transgressive, nearshore facies of both the Bonneterre and Davis Formations, with most of it being the near-shore equivalent of the Davis."

Precambrian

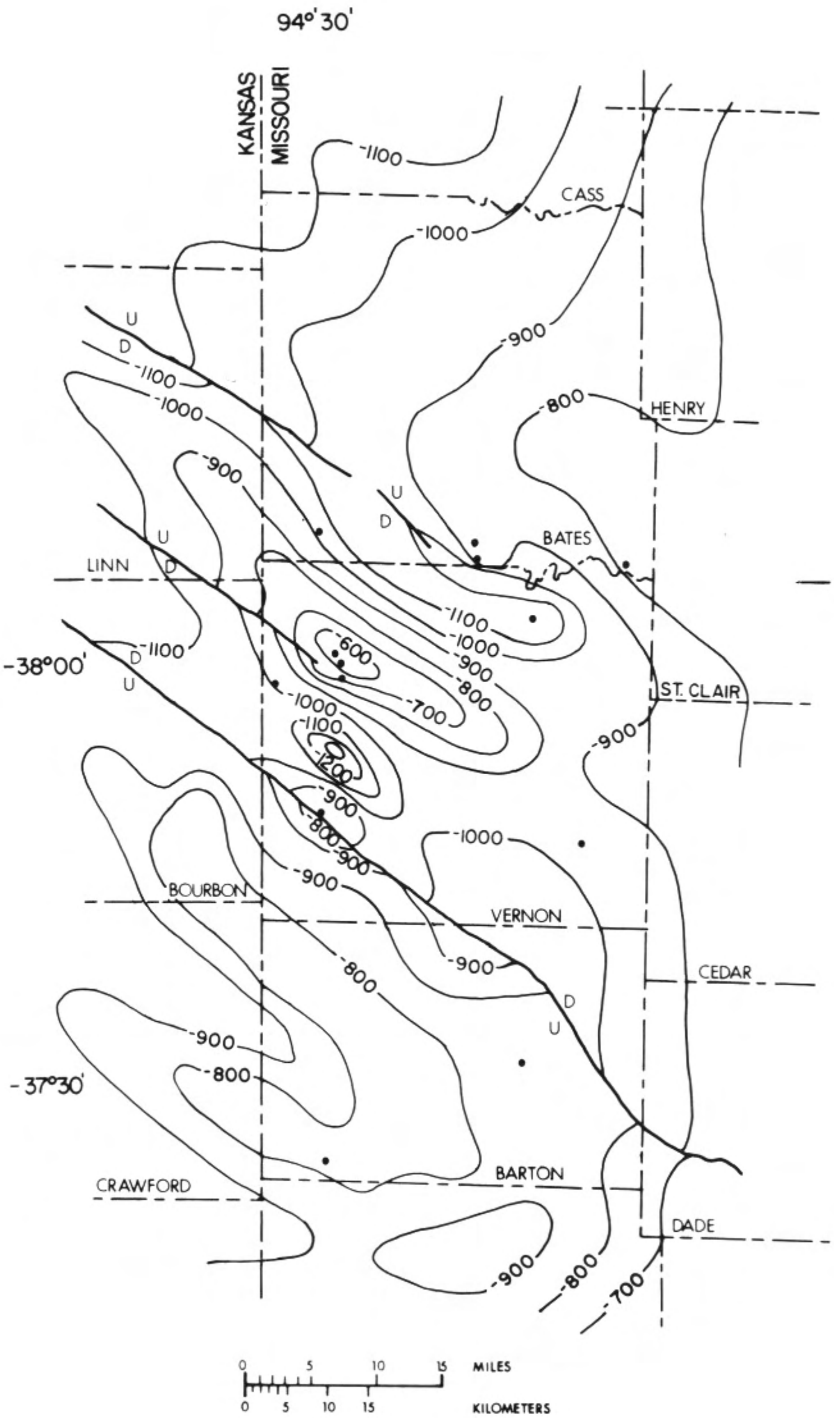
Precambrian rocks in Barton, Vernon, and Bates Counties include metasedimentary rocks, granites, rhyolites, and gneissic granites (Koenig, 1961). The rugged Precambrian topography (fig. 3), consisting of many knobs, hills, ridges, and valleys, shows the effects of tectonic events and differential resistance to erosion (Koenig, 1961; Kisvarsanyi, 1974 and 1975), both of which resulted in northwest-trending structural features. The Precambrian bedrock is the lower, no-flow boundary for the hydrologic system in the area.

STRUCTURE AND PHYSIOGRAPHY

The three-county study area is in the Springfield Plateau and Osage Plains physiographic provinces (fig. 4). The southern part is on the northwestern flank of the Ozark uplift; the northern part is on the southern flank of the Forest City basin; and the Bourbon arch traverses the area from west to east (fig. 4). The regional dip of the underlying strata is approximately 20 ft per mile toward the northwest, except in folded and faulted areas.

The surface topography generally consists of flat plains, with broad, rolling hills in the east. In northern Bates County the resistant limestone of the Kansas City Group forms the Lathrop plain and the many mounds and ridges that rise 75 to 100 ft above it. Erosion of the Kansas City Group and of the less resistant shale and sandstone of the underlying Pleasanton Group formed the Bethany escarpment and Warrensburg platform (Gentile, 1976). Most of Vernon County is a low-relief plain extending from the northeast to the southwest corner of the county. The topographic highs in the southeast and northwest parts of Vernon County have elevations of 1000 and 900 ft, respectively, and slope toward the center of the county. This general surface topography is reflected in the drainage patterns of the major streams in the area (fig. 5). North to south, the major river basins in the three-county area are the Marias Des Cygnes River, Little Osage River, and the Marmaton River.

Barton and southern Vernon Counties contain several low northwest-trending folds, which generally plunge northwestward and have low-angle flanks. There is little surface evidence of these folds, but subsurface mapping of a marker bed, the Short Creek Oolite Member of the Keokuk Limestone, revealed them (McCracken, 1971). In Bates and extreme northeastern Vernon County,



EXPLANATION

● **Well**

—-900— **Bedrock Contour** — Shows altitude of top Precambrian surface. Contour interval 100 feet. National Geodetic Vertical Datum of 1929

D/U **Fault** — D, indicates downthrown side; U, upthrown side

Kansas data modified from Cole (1976); Missouri data modified from Kisvarsanyi (1975).

Figure 3 — Topography of the Precambrian surface in southwestern Missouri and southeastern Kansas.

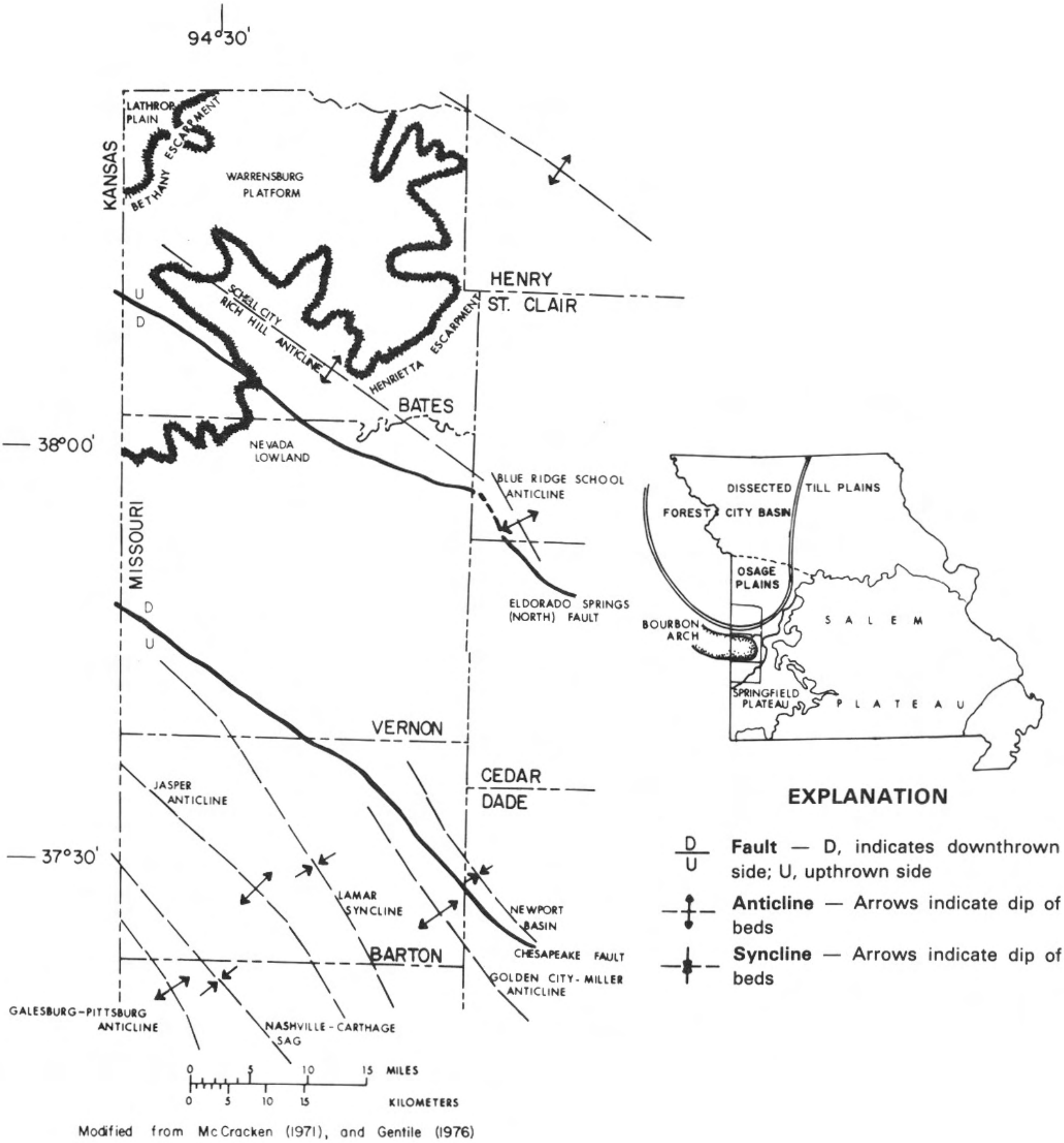


Figure 4 — Geologic structures in Barton, Vernon, and Bates Counties, and physiographic provinces of Missouri.

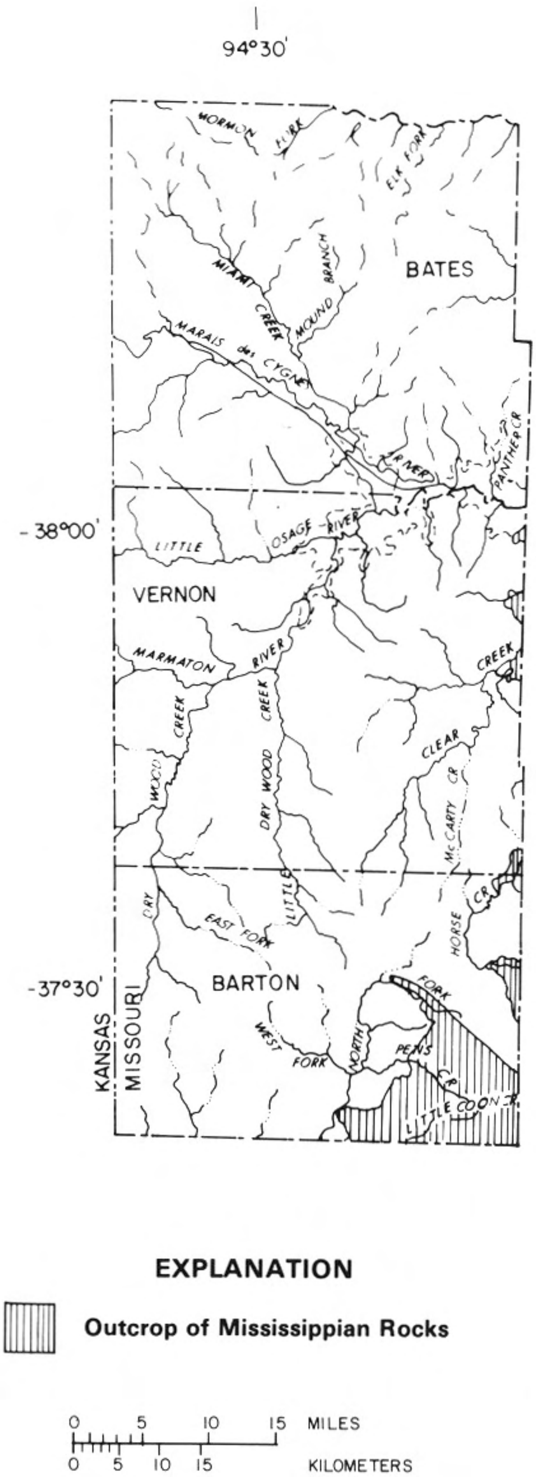


Figure 5 — Major streams.

the Schell City-Rich Hill anticline (fig. 4), one of the major structural features in the study area, follows the typical northwest trend of the folds in Barton County. However, it is asymmetrical, with a steeply dipping southwest limb, and has 150 ft of closure (McCracken, 1971). Pennsylvanian shale and coal beds in this fold, and probably the pre-Pennsylvanian limestone and dolomite, are faulted.

The Eldorado Springs North fault, having an average throw of 150 ft, and downthrown southwestern side, is about 5 mi south of the Schell City-Rich Hill anticline, and parallel to it. Lower Ordovician and Mississippian strata are affected (McCracken, 1971). Pennsylvanian strata in Bates County show possible faulting (Gentile, 1976), indicating the fault may be a subsurface expression of the Schell City-Rich Hill anticline (McCracken, 1971).

McCracken (1971) summarized the work of previous investigations in locating, extending, and dating the Chesapeake fault, the other major fault in the study area. The fault is well developed southeast of the study area, but it was not until 1946 that it was extended. Evidence for the fault was sparse but changes in topography, residual chert, and soil patterns indicated the fault extended into Dade County. In 1965, as part of contouring the base of the Roubidoux Formation, it was determined that the fault extended through Barton and Vernon Counties, to the Kansas state line. During 1924 the Chesapeake fault was dated Late Mississippian, because the Pennsylvanian channel sandstone crossing it was not displaced. The northeastern side of the fault is downthrown (McCracken, 1971).

On plate 1, four hydrogeologic sections and their locations are shown, based on selected geologic well logs. The sections include corresponding water-level or potentiometric-surface profiles of the Pennsylvanian, Mississippian, and Cambrian-Ordovician aquifers. The formations of the Meramecian and Osagean Series are treated as single units within each series because the formations are difficult to differentiate on well logs. The generalized geologic section in Barton, Vernon, and Bates Counties (table 1) identifies map and section symbols for each formation. Sections A-A' through C-C' parallel the regional dip for each of the three counties; section D-D' is a longitudinal section from just south of Barton County to the middle of Bates County.

Several geologic and topographic structures are evident: for example, in Bates County (section A-A'), the Bethany escarpment and the northwestward dip of the beds. Because of poor water quality, there are few deep wells in northwest Bates County. Section A-A' could not be completed below the top of the Meramecian Series in this area.

As shown in section B-B', the dip of the beds tends to increase toward the northwest corner of Vernon County. The Northview Formation thickens southeastward. Section C-C' shows the effects of anticlines and synclines on topography in Barton County; the Golden City-Miller anticline is especially notable. Section D-D' extends longitudinally across the study area and generally shows a slight northward dip of the beds. Thinning of the Cotter and Jefferson City Dolomites in Vernon County, caused by the Bourbon arch (fig. 4) also is evident. North of the Eldorado Springs North fault, the strata begin to dip steeply into the Forest City basin (fig. 4), which is bordered on the south by the Bourbon arch. Accumulation of sediments in the basin and across the arch throughout the Middle and Late Pennsylvanian account for the thickened Pennsylvanian beds in Bates County.

GROUNDWATER

The quantity of water yielded to a well depends on the hydraulic properties of the aquifer or aquifers open to it. Many carbonate units in the study area show the effects of subsurface solution weathering, causing them to have substantially larger hydraulic conductivities than unweathered units. Thickness and degree of cementing of sandstone beds, recharge from outcrop areas, and intra-aquifer leakage also affect the hydraulic properties of the aquifers.

Description of Aquifers and Confining Beds

Throughout most of Barton, Vernon, and Bates Counties there are three distinct aquifers. They are not limited to a single formation and can be differentiated in terms of depth, yield, and specific capacity. In this report, they are grouped according to major rock units and designated the Pennsylvanian aquifer, the Mississippian aquifer, and the Cambrian-Ordovician aquifer. Water quality in each deteriorates northwest of a sinuous line passing approximately from northwest Barton County to southeast Bates County. Due to this variation, different aquifers are used in different places throughout the study area.

Pennsylvanian Aquifer

The Pennsylvanian rocks are referred to as an aquifer in this report because they provide water, primarily for domestic farm use, in parts of northwestern Vernon County and much of Bates County. The general effect of the alternating Pennsylvanian shales, clays, and sand layers, however, is that of a leaky confining bed to the underlying Mississippian aquifer.

Yields to wells in the Pennsylvanian aquifer range from less than 1 gpm on the west side of the study area to as much as 40 gpm locally. Specific capacities range from less than 0.1 to about 3 gallons per minute per foot of drawdown (gpm/ft). Due to the complex lithology of the Pennsylvanian rocks, favorable water-producing zones are not present in all areas. Locally, moderately thick sand in the Cherokee Group yields small quantities of water. Some water can also be obtained from fractured limestone beds.

The Pennsylvanian aquifer, which crops out throughout most of the study area, varies considerably in thickness. In northwest Bates County, where Missourian rocks are also present, the maximum thickness is about 720 ft. The system thins southeastward, and in several locations in eastern Vernon and Barton Counties, Pennsylvanian strata are absent and the Mississippian System crops out (fig. 6).

Mississippian Aquifer

The Mississippian aquifer is widely used in Barton and Vernon Counties and parts of Bates County. It comprises all formations between the base of the Cherokee Group and the top of the Kinderhookian Series, including the Warsaw Formation, the Keokuk and Burlington Limestones, and the Elsey, Reeds Springs, and Pierson Formations. The Keokuk and Burlington Limestones constitute the most productive unit.

The altitude of the top of the Mississippian aquifer and its thickness are shown in figures 7 and 8. The structural map (fig. 7) of the Mississippian aquifer shows the dip to be northwestward. Several geologic structures, particularly the Schell City-Rich Hill anticline, Eldorado Springs North fault, and the Chesapeake fault, are evident on the map. Subtracting the altitude of the top of the Mississippian aquifer from that of the land surface at the same place, gives an estimation of the depth to the top of the aquifer.

Although aquifer thickness (fig. 8) is relatively uniform, it has a maximum of more than 390 ft in central Vernon County and a minimum of less than 100 ft in northeastern Bates County.

The Mississippian formations in the study area are mostly cherty carbonates with minor shale. Secondary permeability from fractures and solution-enlarged openings in these rocks increases groundwater productivity. In places, a 5- to 20-ft layer of weathered, residual detritus is at the top of the Mississippian section. This ancient weathered zone, where well-developed, can yield as much as 30 gpm.

Yields to wells in the Mississippian aquifer range from 3 to about 60 gpm and average about 15 to 20 gpm. Based on production data provided by well drillers, specific capacities range from about 0.2 to 0.5 gpm/ft and average about 0.35 gpm/ft.

Confining Beds

The Kinderhookian Series and the underlying Devonian-Chattanooga Shale form the confining layer separating the Mississippian aquifer from the Cambrian-Ordovician aquifer. The Kinderhookian Series includes the Northview, Sedalia, and Compton Formations of the Chouteau Group. The Northview Formation is dominantly a sandy, silty shale that is occasionally dolomitic. For a hydrologic model of Center Creek basin near Joplin, Harvey and Emmett (1980) assigned a vertical hydraulic conductivity of 5.0×10^{-10} ft/s to the

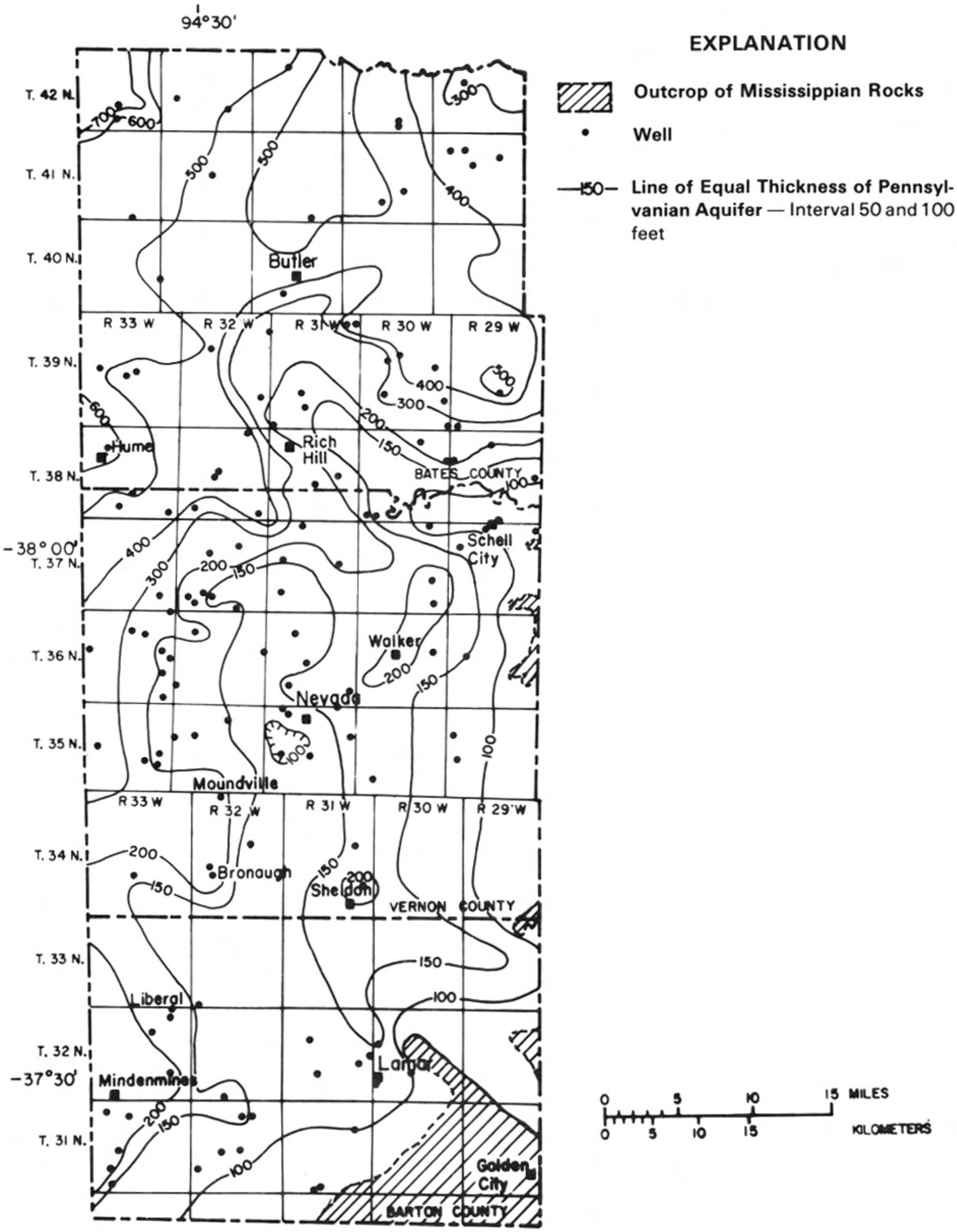


Figure 6 — Thickness of the Pennsylvanian aquifer.

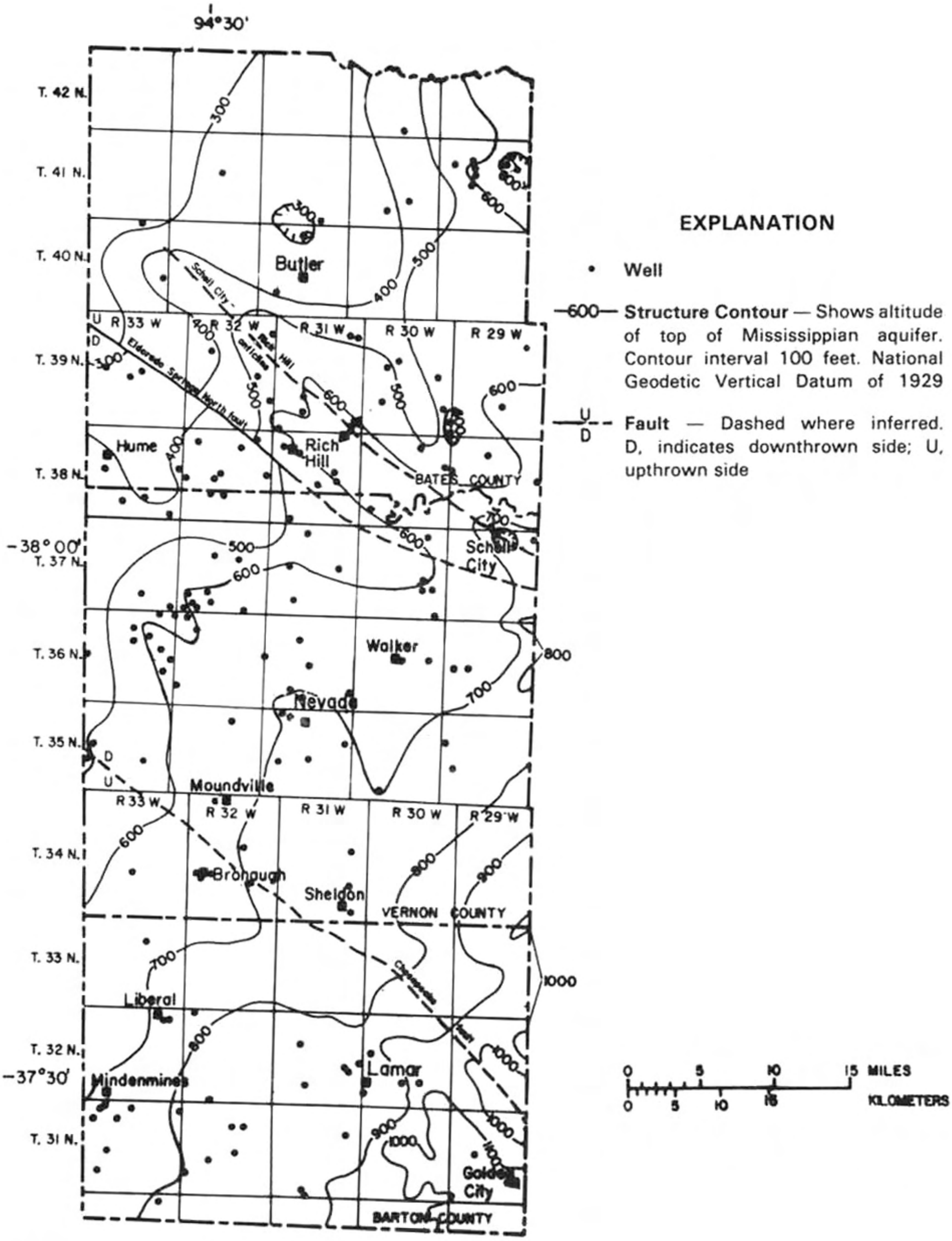
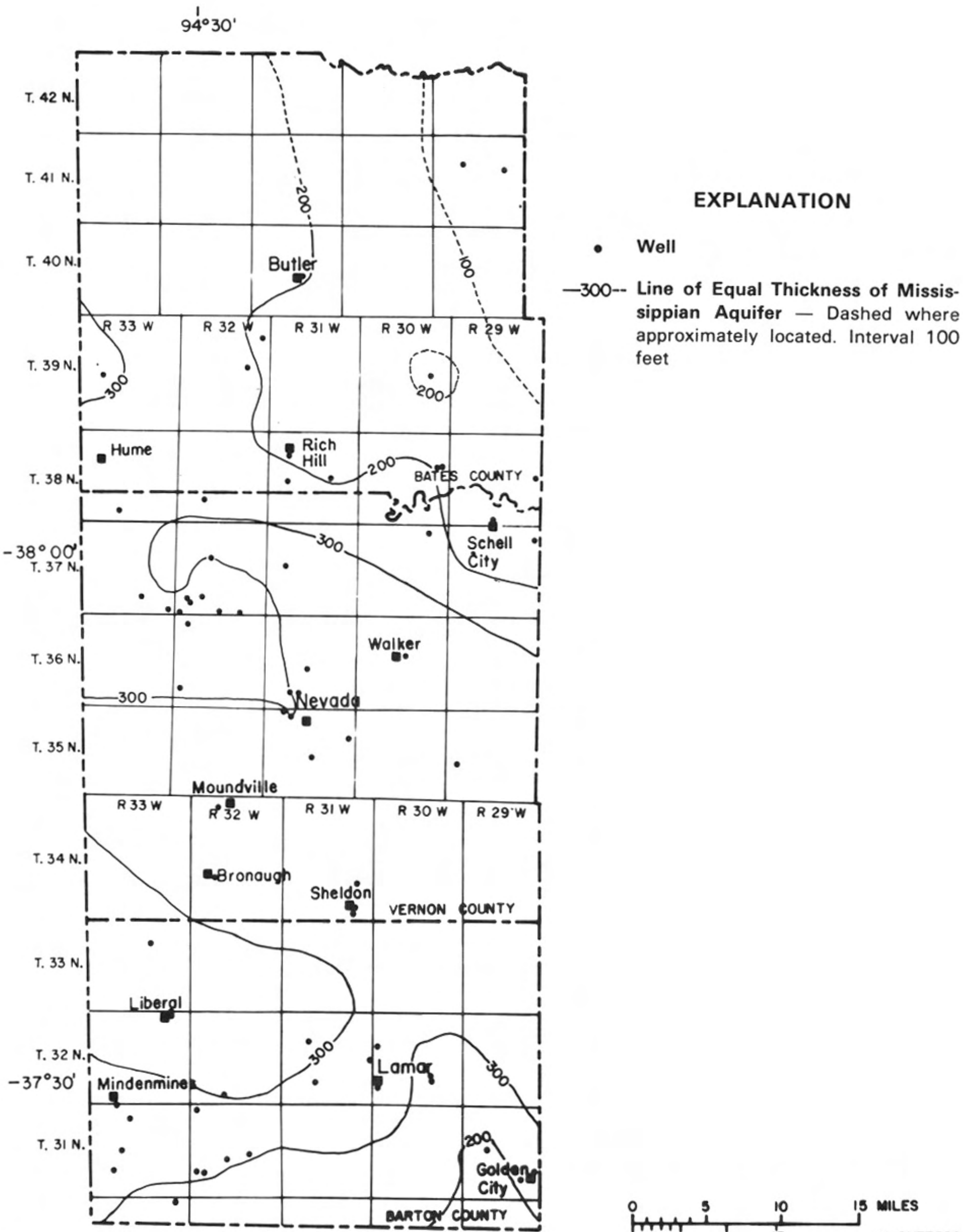


Figure 7 — Altitude of the top of the Mississippian aquifer.



Modified from J.L. Imes (U.S. Geological Survey, written commun., 1983)

Figure 8 — Thickness of the Mississippian aquifer.

Northview Formation. The Sedalia Formation is a finely crystalline dolomitic limestone; the Compton typically is a finely crystalline limestone. All the Kinderhookian Series is considered to be confining; however, some beds are less permeable than others. The Northview Formation, the least permeable unit, is the principal confining unit within the series. The Chattanooga Shale is present in only a few localized areas and is not considered to add significantly to the confining capabilities of the Kinderhookian Series. For this reason, the Chattanooga shale is not differentiated from the Kinderhookian in the following discussion.

The altitude of the top of the Kinderhookian Series (fig. 9) indicates the dip of this confining layer is northwestward. The effect of the Schell City-Rich Hill anticline, Eldorado Springs North fault, and the Golden City-Miller anticline on this layer is shown on this map. Altitude of the confining layer is highest on the Golden City-Miller anticline, in southeast Barton County, and is expected to be lowest in northwest Bates County; however, no well data are available for verification.

As shown in figure 10, thickness of the Kinderhookian Series increases northward. In southwestern Bates County the measured maximum thickness of the confining layer is 215 ft, because the Devonian beds are significantly thicker. Thinning of the Northview and Compton Formations in southern Barton County causes the thickness of the Kinderhookian to be less than 40 ft.

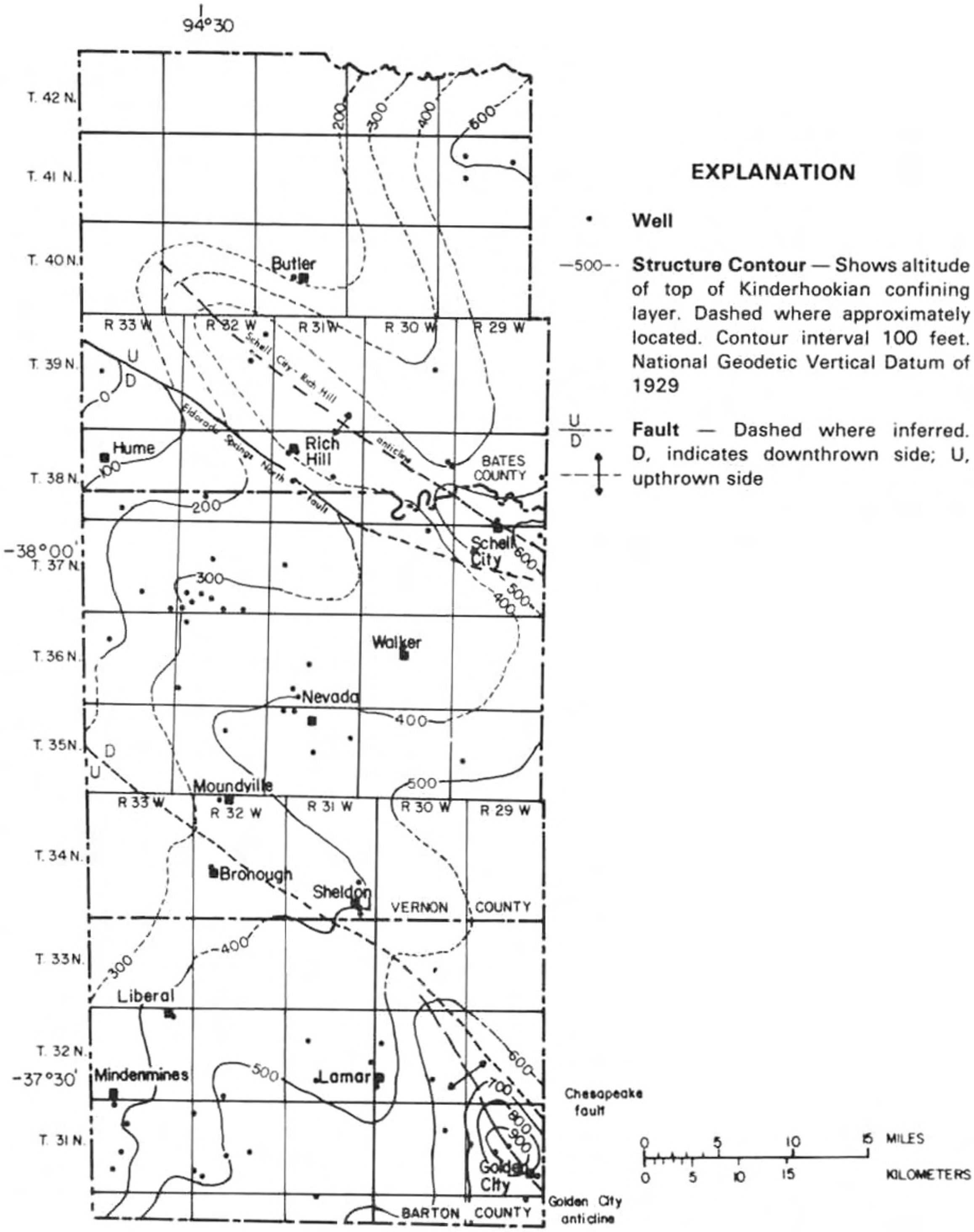
Because the Northview Formation is the principal Kinderhookian confining unit, a thickness map of it is shown in figure 11. The map shows a thickness of about 80 ft in northeast Barton and southeast Vernon Counties. North and south of this area, the formation thins. In northern Vernon County the thickness is less than 10 ft; in southern Barton County it decreases to approximately 20 ft. The Northview is virtually absent in Bates County.

Cambrian-Ordovician Aquifer

After Pennsylvanian sediments were deposited over central Missouri, the Ozarks were uplifted and area subjected to subaerial erosion. When the overlying beds were removed, the Cambrian-Ordovician rocks became exposed in the Salem Plateau area. Because these rocks dip away radially from the uplifted area, the Salem Plateau is the recharge area of a confined aquifer system (Siebenthal, 1915). In the study area the Cambrian-Ordovician aquifer is bounded below by Precambrian rocks and above, in most of Barton and Vernon Counties, by the relatively impermeable Kinderhookian Northview Formation.

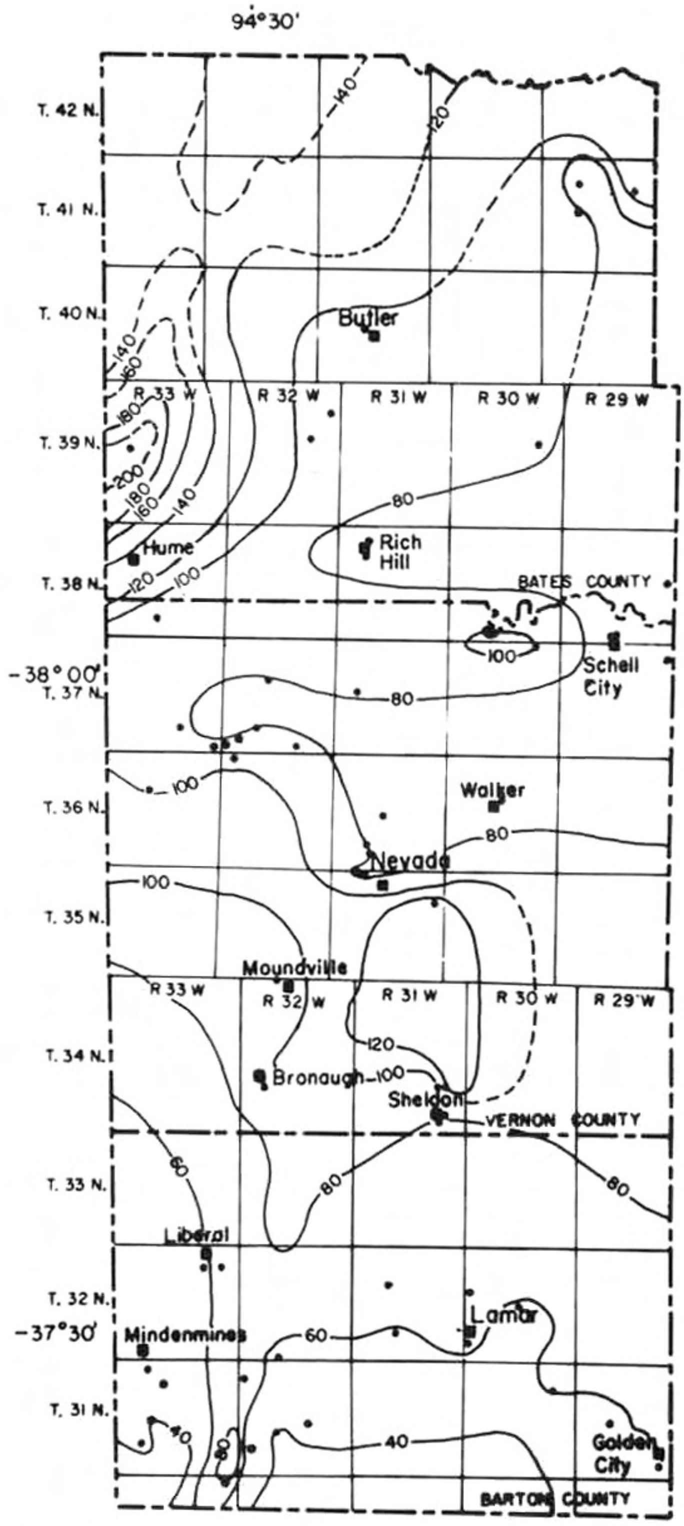
The Cambrian-Ordovician aquifer comprises the Cotter and Jefferson City Dolomites, Roubidoux Formation, Gasconade Dolomite, Eminence Dolomite, and Potosi Dolomite. Wells completed in the Cambrian-Ordovician aquifer have the largest yields in the study area and typically are used for municipal, industrial, and irrigation water supplies. Wells producing from this aquifer usually are cased in Mississippian rocks or in the Cotter or Jefferson City Dolomite and are open to several water-producing zones of multiple aquifers.

A structure-contour map of the top of the Cambrian-Ordovician aquifer (fig. 12) and a thickness map of the aquifer (fig. 13) were prepared for the study area. The structure-contour map shows how several geologic structures affect the aquifer. The altitude of the aquifer is highest in southeastern Barton County, because of the Golden City-Miller anticline; it is lowest in Bates County, on the downthrown side of the Eldorado



Modified from McCracken (1971)

Figure 9 — Altitude of the top of the Kinderhookian confining layer.



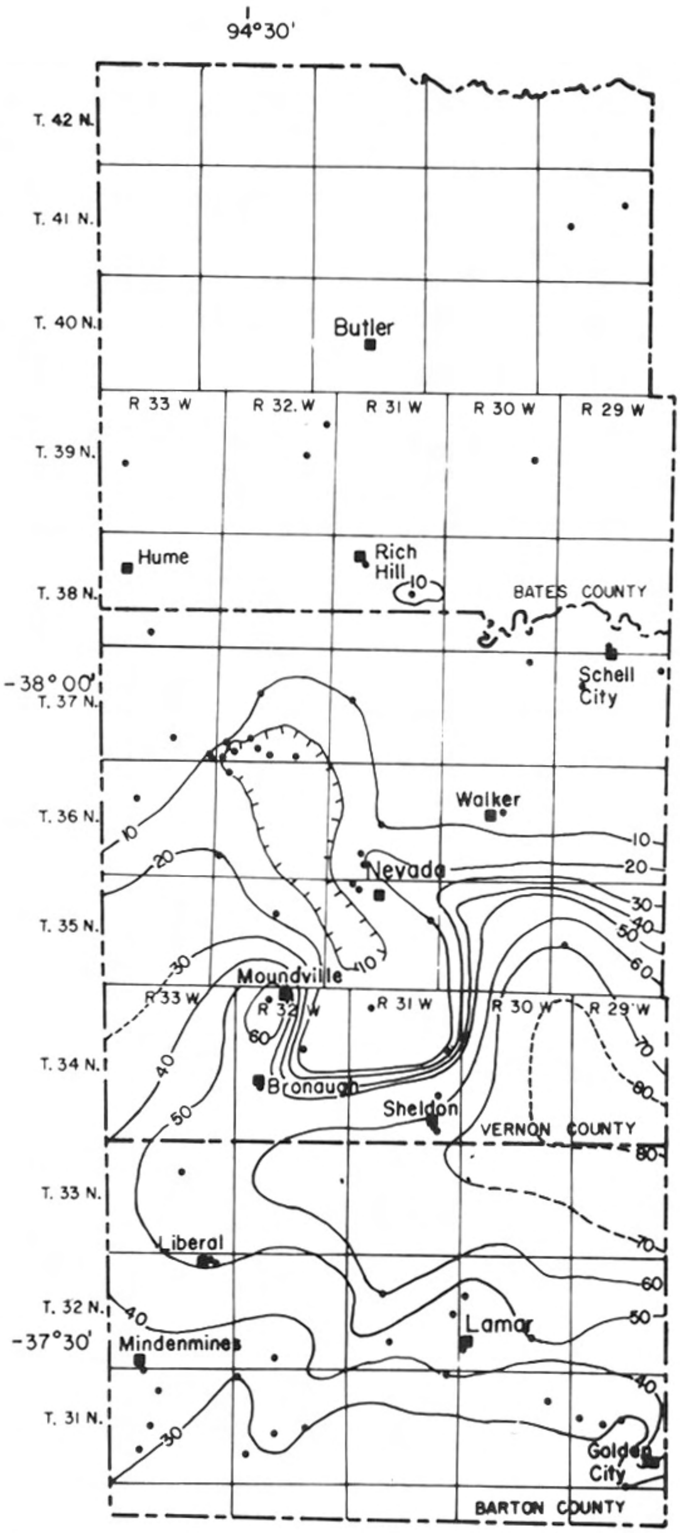
EXPLANATION

• Well

—80-- Line of Equal Thickness of Kinderhookian Series — Dashed where approximately located. Interval 20 feet

Modified from J.L. Imes (U.S. Geological Survey) written commun., 1983)

Figure 10 — Thickness of the Kinderhookian confining layer.



EXPLANATION

• **Well**

—20-- **Line of Equal Thickness of Northview Formation** — Dashed where approximately located. Interval 10 feet

Figure 11 — Thickness of the Northview Formation.

Springs North fault. The thickness map shows the aquifer has a maximum thickness of more than 1100 ft in southeastern Barton County and thins northwestward to less than 500 ft in northwestern Bates County.

The Cotter and Jefferson City Dolomites typically are cherty and contain minor interbedded sandstone; usually they yield only a few gallons per minute. Wells completed in the upper 50 to 75 ft of the Roubidoux Formation, a sandy dolomite, usually yield 25 to 100 gpm. Wells open to the entire thickness of the Roubidoux may yield 50 to 250 gpm and have specific capacities of 0.4 to 17 gpm/ft. Yields and specific capacities are from drillers' logs at the Missouri Department of Natural Resources; all wells used are in the study area.

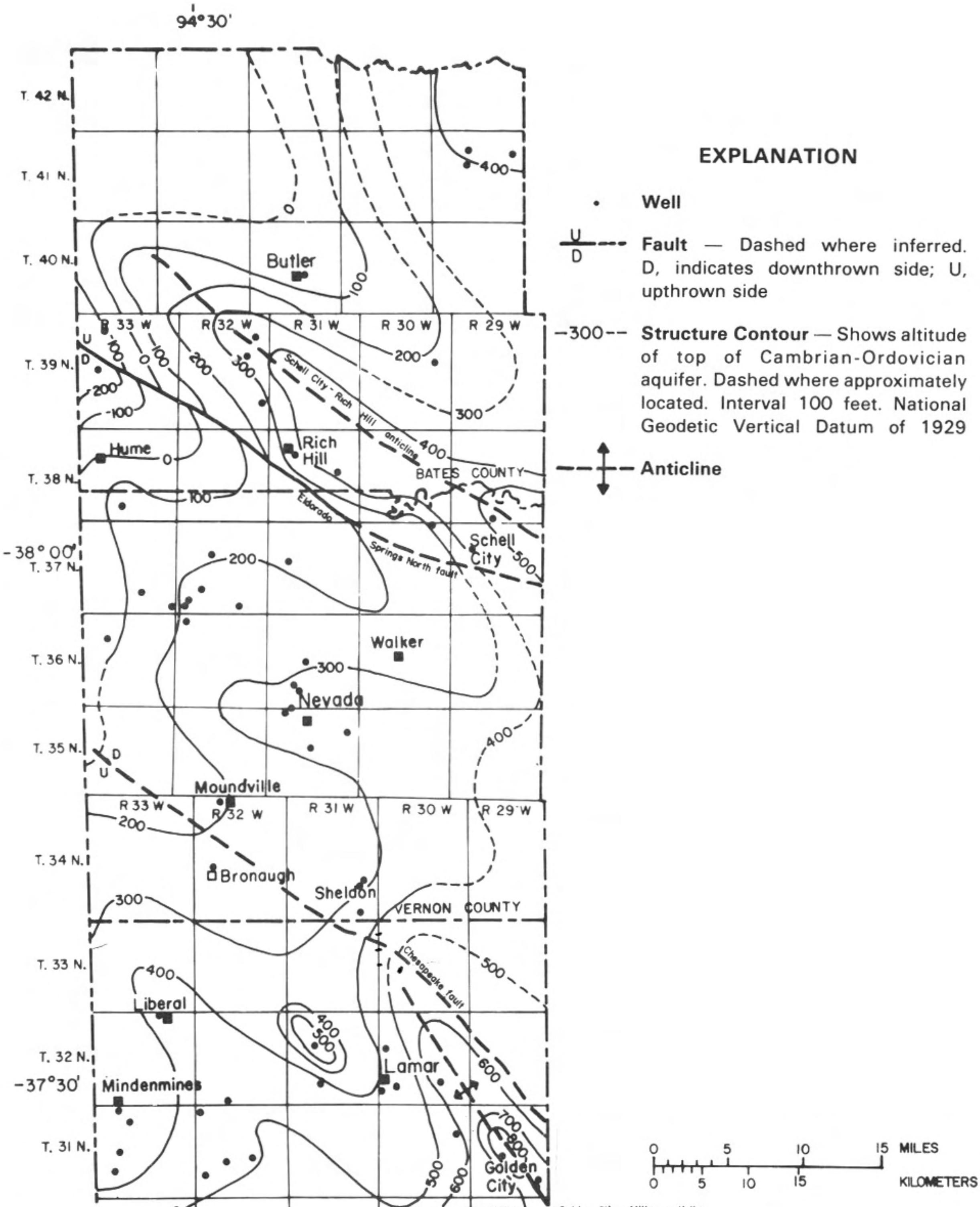
In this area the upper part of the Gasconade Dolomite is moderately productive, yielding 250 to 600 gpm and having specific capacities of as much as 5.6 gpm/ft. Wells drilled into the lower Gasconade Dolomite are among the largest producers in the area; yields are 350 to more than 1000 gpm. Specific capacities of these wells range from 20 to 50 gpm/ft.

The few wells drilled into the Eminence Dolomite in the study area produce 500 to about 1200 gpm, with specific capacities of 17 to 40 gpm/ft. Because the Potosi Dolomite is quite thin in the area and few wells are drilled into it, it is difficult to estimate its water potential. No producing wells in the area are open to formations deeper than the Potosi Dolomite, but in surrounding areas, wells drilled through the Potosi have yielded as much as 1300 gpm.

Few data are available to determine the vertical component of groundwater flow within the Cambrian-Ordovician aquifer. A well installed by the city of Nevada, however, provided opportunities for measuring static water levels at different depths during drilling (table 2). Measurements show that water in the well rose 34 ft when the Jefferson City Dolomite was penetrated. Thereafter, depth to water remained at 128 ft below land surface during drilling in the Jefferson City, Roubidoux, upper Gasconade, and lower parts of the Gasconade. The data, although only recorded from one well, indicate that these formations are hydraulically connected.

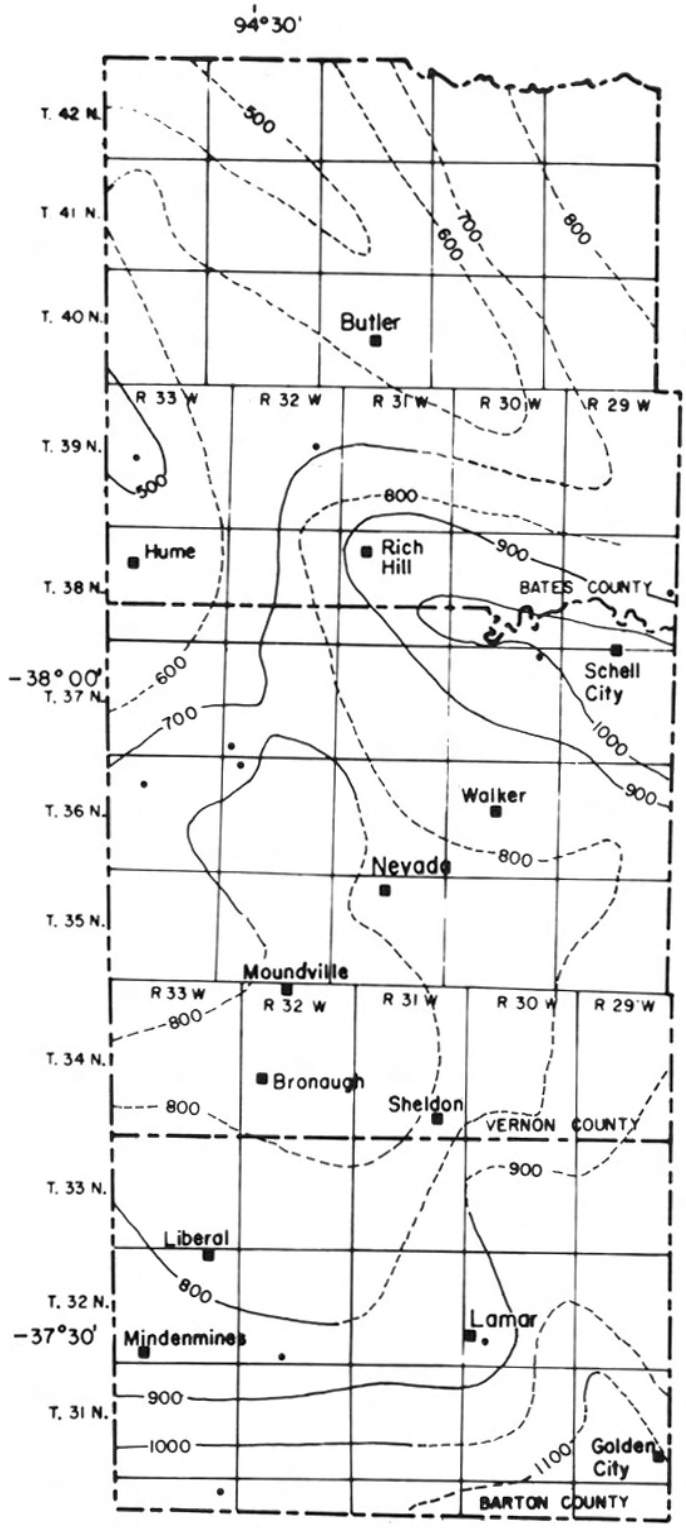
Aquifer Tests

The Missouri Division of Geology and Land Survey has only limited aquifer-test data available for the study area. Tests that were made are not ideal for several reasons. The large-yielding carbonate aquifers are not homogenous and isotropic. It was not economically feasible to drill observation wells nearby, because the tested wells are 785 to 1100 ft deep. Secondary permeabilities from solution-enlarged fractures and bedding planes cause transmissivity and storage coefficients to vary vertically and laterally. The contractor usually made the tests after drilling ended but before each well was fully developed and a permanent pump installed. Generally each test lasted less than 6 hours, and the test pumping rate was only a fraction of that of a permanent pump. Such factors limit the value of the data obtained from the aquifer tests, because boundary conditions generally only become apparent after extended pumping. In addition, because the wells penetrate and produce from several zones in several formations, it is difficult to determine the hydraulic characteristics of specific units. Aquifer characteristics calculated from these large-production, multiaquifer wells are assumed to be those of the Cambrian-Ordovician aquifer. To support this



Modified from McCracken (1971)

Figure 12 — Altitude of the top of the Cambrian-Ordovician aquifer.



EXPLANATION

• Well

—800-- Line of Equal Thickness of Cambrian-Ordovician Aquifer — Interval 100 feet

0 5 10 15 MILES

0 5 10 15 KILOMETERS

Modified from J.L. Imes (U.S. Geological Survey, written commun., 1983)

Figure 13 — Thickness of the Cambrian-Ordovician aquifer.

TABLE 2

Static water levels measured during drilling of Missouri Public Service Well 3 at Nevada
(Data from Missouri Division of Geology and Land Survey)

Location	Well depth (ft)	Casing depth (ft)	Altitude of land surface (ft)	Depth to water (ft)	Depth drilled (ft)	Formation penetrated
T. 35 N., R. 31 W. sec. 5dba	1,100	275	851	162	350	Keokuk and Burlington
				128	520	Jefferson City
				128	770	Roubidoux
				128	825	Upper part of Gasconade
				128	1,005	Lower part of Gasconade

approach, it is assumed that typical wells open to the Mississippian aquifer yield 15 to 20 gpm, whereas those open to the Gasconade Formation yield 350 to 1000 gpm. When wells penetrate deeper formations, their yields increase substantially. Additional yields supplied by the Mississippian aquifer are considered negligible; however, in the calculations, the increased saturated thickness that results from including the Mississippian aquifer decreases the calculated transmissivity of the Cambrian-Ordovician aquifer.

If no observation wells are present, a pumped well is used to make water-level measurements. Because it generally is not possible to determine the effective radius of a pumped well, the storage coefficient cannot be determined accurately. Generally, specific capacity is the only quantitative factor obtained for a well, and it can be used to calculate transmissivity, but, because of partial penetration of the aquifer by the well, well losses, and geologic boundaries, calculated transmissivity, so determined, is generally less than actual transmissivity.

During the summer of 1982, on the western side of the study area, the Missouri Division of Geology and Land Survey made aquifer tests in 14 wells producing from Pennsylvanian rocks. The wells were dewatered as quickly as possible and recovery data collected. Well yields were calculated from recovery rates and well diameters. Storage coefficients could not be determined. Because the tests were brief, reliability of the quantitative values obtained for transmissivity and hydraulic conductivity is doubtful. However, the tests provide a qualitative estimate of the hydraulic properties of the Pennsylvanian aquifer; they indicate that the aquifer on the west side of the study area yields little water, usually less than 1 gpm, and that the shale and clay are relatively impermeable.

No aquifer-test data are available for the Mississippian aquifer in the study area or similar surrounding areas. However, solution development along joints and bedding planes could cause increased hydraulic conductivity.

Aquifer tests indicated that the Mississippian and Cambrian-Ordovician aquifers are leaky artesian or semiconfined. Semiconfined conditions are shown by deviations from the aquifer response predicted by the Theis solution. Despite presence of confining beds, there is probably some groundwater circulation throughout the Mississippian and Cambrian-Ordovician aquifers.

Aquifer-test data are available from two wells producing from the Mississippian to the Roubidoux Formation of the Cambrian-Ordovician aquifer. Vernon County Public Water-Supply District well 1, at Moundville (sec. 5, T. 34 N., R. 32 W.), is 785 ft deep and is open from the base of the Warsaw Formation to about 25 ft into the Roubidoux. The well was pumped at 60 gpm; the transmissivity was calculated to be 470 ft^2/day. Vernon County Public Water-Supply District 4 well 1 (sec. 19, T. 35 N., R. 29 W.) is 800 ft deep and is open from the base of the Keokuk-Burlington Limestone to the base of the Roubidoux. It was pumped at 410 gpm; the transmissivity was calculated to be 11,000 ft^2/day. Because of productive zones near the base of the Roubidoux Formation, yield for this well is much larger than that of the well at Moundville.

Aquifer-tests from two irrigation wells in Barton County indicate a large transmissivity for the lower part of the Gasconade Dolomite. S.R. Weidner's irrigation well 2 (sec. 30, T. 31 N., R. 33 W.) is 1100 ft deep and is open from the top of the Warsaw Formation to about 30 ft into the lower part of the Gasconade. It was pumped at 525 gpm, with a transmissivity of 5800 ft^2/day. Carl Compton's irrigation well 1 (sec. 28, T. 32 N., R. 31 W.) is 1020 ft deep and is open from the top of the Warsaw Formation to 35 ft into the lower part of the Gasconade. It pumped at 530 gpm, with a transmissivity of 12,000 ft^2/day. Paul Schnelle's irrigation well 3 in western Dade County (sec. 18, T. 30 N., R. 28 W.), also completed in the lower part of the Gasconade Dolomite, was pumped at 500 gpm, with a transmissivity of 1400 ft^2/day.

Aquifer-test data are unavailable for wells in the study area that are open to Cambrian strata. Data are available for two wells in northern Jasper County that are completed in the Eminence Dolomite. Jasper County Public Water-Supply District well 2 (sec. 4, T. 29 N., R. 32 W.) is 1225 ft deep and is open from the lower part of the Jefferson City Dolomite to 130 ft into the Eminence. The well was pumped at 280 gpm, with a relatively small transmissivity, 370 ft^2/day. Fred Knell's irrigation well (sec. 1, T. 29 N., R. 32 W.), also 1225 ft deep, is open from the middle part of the Jefferson City Dolomite into the Eminence Dolomite. The well was pumped at 440 gpm, with a transmissivity calculated to be 1700 ft^2/day.

Groundwater Recharge, Movement, and Discharge

Pennsylvanian Aquifer

Precipitation is the principal source of recharge for the Pennsylvanian aquifer. Unlike most of the Springfield Plateau and Salem Plateau (fig. 4), where sinkholes and losing streams contribute much groundwater recharge, these features are virtually absent in the study area. Relatively few sinkholes are in the western part of the State, where Pennsylvanian rocks crop out and where Mississippian limestone has been exposed for a relatively short time. There are no losing streams, because the Pennsylvanian shale and clays have minimal permeability, and surface and near-surface carbonate units lack karst development.

Depending on the amount of precipitation, water levels fluctuate considerably. Shallow wells occasionally are dry during droughts and flow during wet periods.

During the summer of 1982, the Missouri Division of Geology and Land Survey made a mass water-level measurement that concentrated on the Pennsylvanian aquifer in west-central Vernon County (fig. 14). Measurements indicated the water table, as shown in figure 14, reflects the topographic surface. A summary of the water-level data is in the Supplemental Data section in this report. Measured wells vary from shallow, hand-dug wells to those drilled approximately 200 ft deep. In nearly all, depth to water generally was less than 15 ft in low-lying areas and as much as 40 ft in wells on topographic highs. These data indicate the Pennsylvanian aquifer is under water-table conditions. During this mass water-level measurement, however, three wells deeper than 100 ft had depths to water of more than 70 ft. These wells probably represent localized areas with alternating sandstone and shale confining layers.

Historical water-level measurements in Bates County show the same general conditions as in west-central Vernon County, except depth to water is slightly greater. In eastern Bates County several wells are drilled to the base of the Cherokee Group. Depth to water in them is much greater than the general relation would indicate for the Pennsylvanian aquifer. Samples from these wells show the water is from the Pennsylvanian aquifer, not ascending water from the Mississippian aquifer.

In Bates County, where several deep and shallow wells completed in the Pennsylvanian aquifer are within a mile of each other, the water level in the deep well is nearly 100 ft lower. These data, together with the water-level measurements from the three deep wells in Vernon County and the deep wells in eastern Bates County, reinforce the concept that, at least locally, confined conditions exist in the Pennsylvanian aquifer at depth. Because only limited data are available on this deeper, confined water in the Pennsylvanian aquifer, no water-level map was constructed to show this condition.

Pennsylvanian-aquifer data are sparse in Barton and eastern Vernon County where the system becomes thin. In these areas, because of the superior quality of water from the Mississippian aquifer, wells completed in the Mississippian aquifer are more desirable.

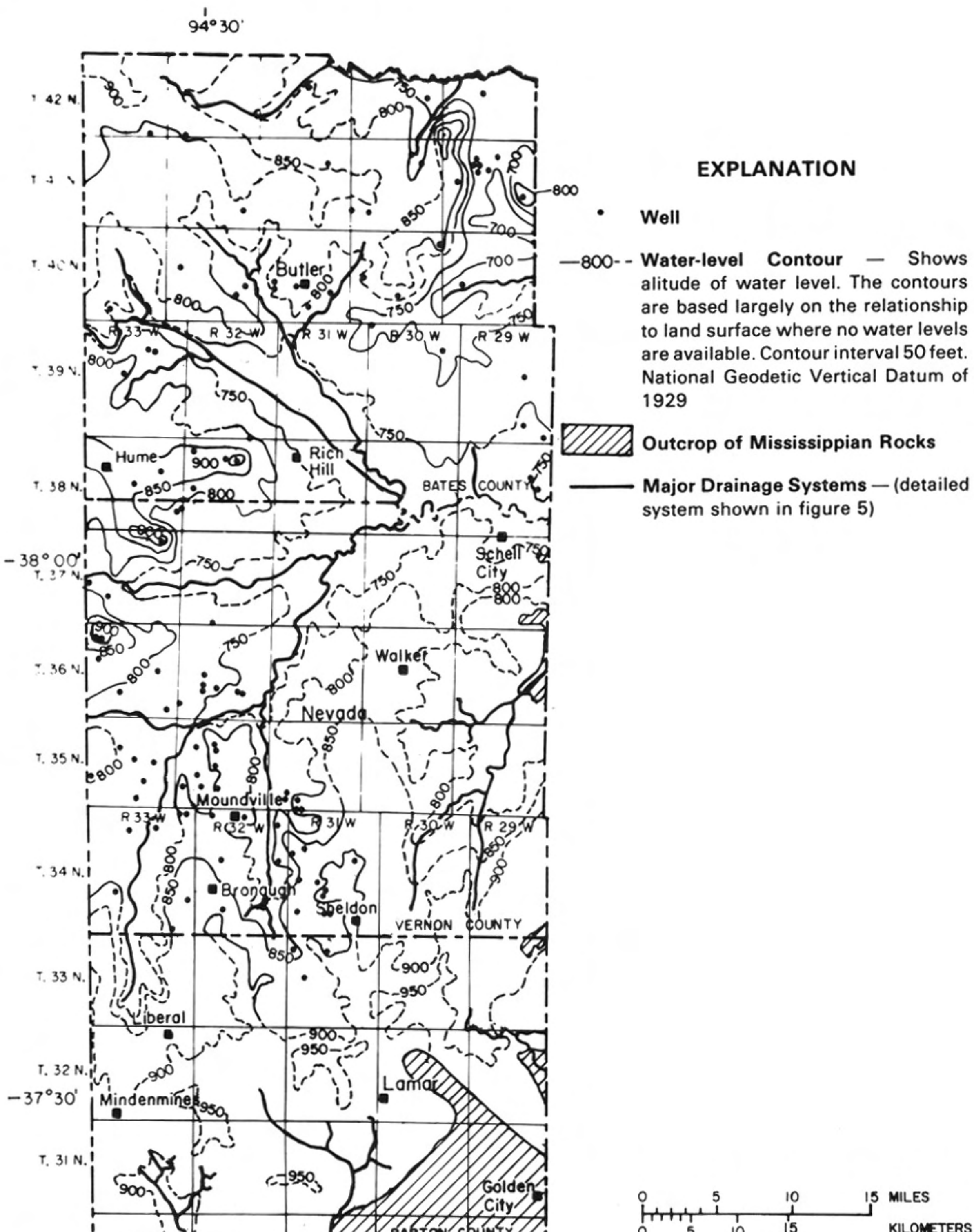
The direction of water movement in the Pennsylvanian aquifer is similar to that of the surface-water drainage in the study area. The groundwater moves from topographic highs toward topographic lows (perpendicular to the water-level contours).

Natural discharge of water from Pennsylvanian strata may occur as evapotranspiration; as downward movement into the Mississippian aquifer where conditions allow; or, during wet periods, as seepage along stream channels and from springs. Artificial discharge primarily is from domestic wells in the area. It appears that over a long time, discharge is balanced by recharge and water levels do not change significantly.

Mississippian Aquifer

The primary source of recharge to the Mississippian aquifer is groundwater movement into the study area from the outcrop area southeast of Barton County. Potentiometric maps of the study area show that water in the Mississippian aquifer moves from the outcrop area to the south and east, northwestward through Barton, Vernon, and Bates Counties, toward Kansas. Water-level measurements show that the Mississippian aquifer is confined and that the potentiometric surface is below water levels in the Pennsylvanian aquifer. Where overlying Pennsylvanian shale and clay form a leaky confining layer, water from the Pennsylvanian aquifer probably is recharging the Mississippian aquifer.

A hydrograph provided by the Missouri Division of Geology and Land Survey illustrates how the water level in a well completed in the Mississippian aquifer responds to changes in precipitation (fig. 15). The hydrograph is from a well, in southeast Vernon County (sec. 6cac, T. 35 N., R. 29 W.), in which a



Base from U.S. Geological Survey Lawrence
1:250,000, 1974, and Joplin 1:250,000, 1973

Figure 14 — Altitude of water level in the Pennsylvanian aquifer during 1982.

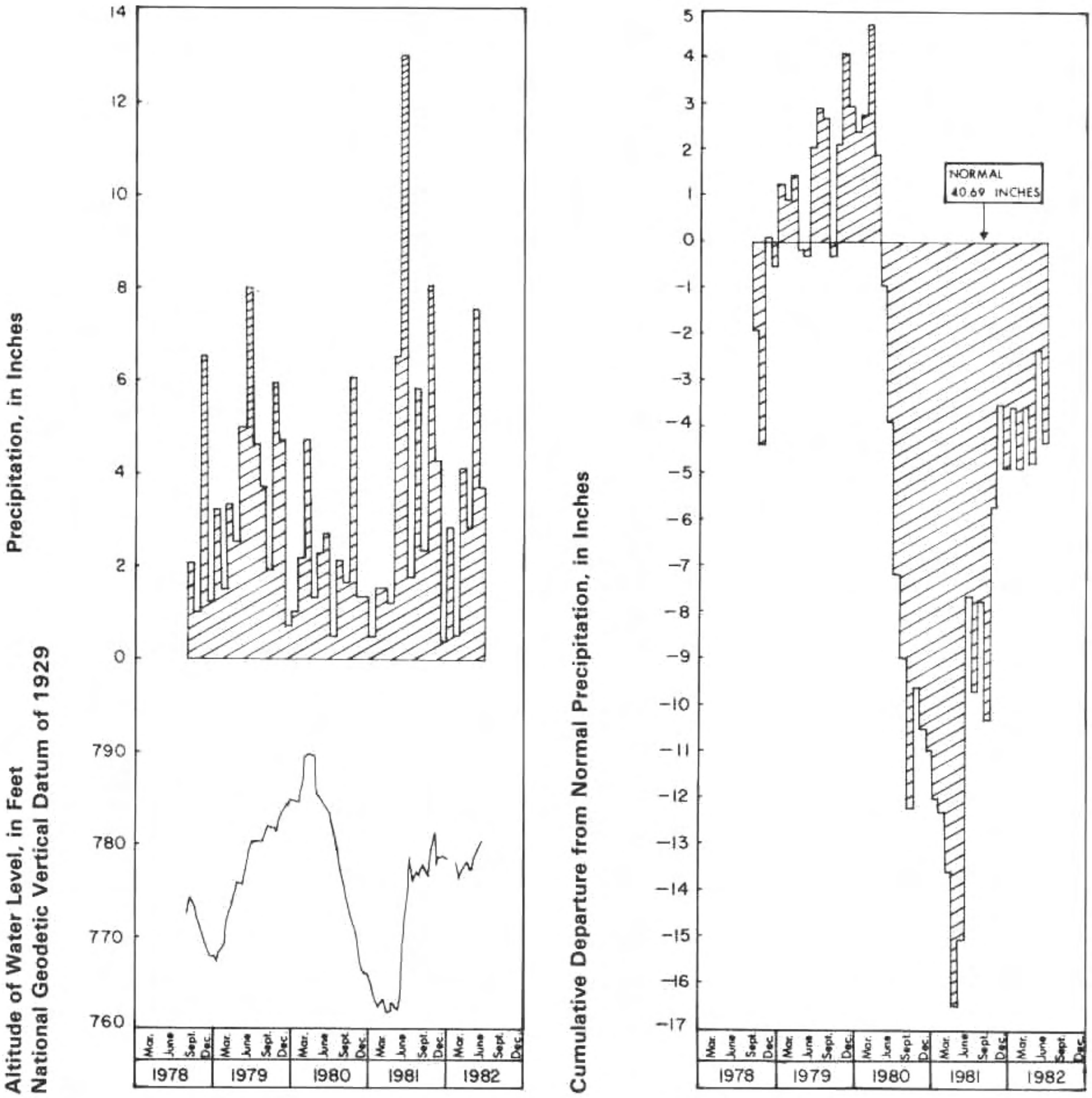


Figure 15 — Correlation of precipitation and water level in a well completed in the Mississippian aquifer in southeast Vernon County.

continuously operating water-level recorder is installed. Although no log is available for this well, the owner reported to the Missouri Division of Geology and Land Survey that the well is approximately 525 ft deep and contains 100 ft of casing, which should be sufficient to case out the Pennsylvanian aquifer, leaving only the Mississippian strata open (R.D. Knight, Missouri Division of Geology and Land Survey, oral commun., 1982). Water levels recorded in this well are approximately 40 ft higher than expected for the Mississippian aquifer; perhaps water from the Pennsylvanian aquifer is entering the well. The recorder has been operating since September 1978, a span sufficient to show the sensitivity of the aquifer to local climatic conditions. During the drought of 1980, the water-level decline was approximately 23 ft. After the drought, greater-than-normal precipitation, during May and June 1981, resulted in an abruptly increased water level.

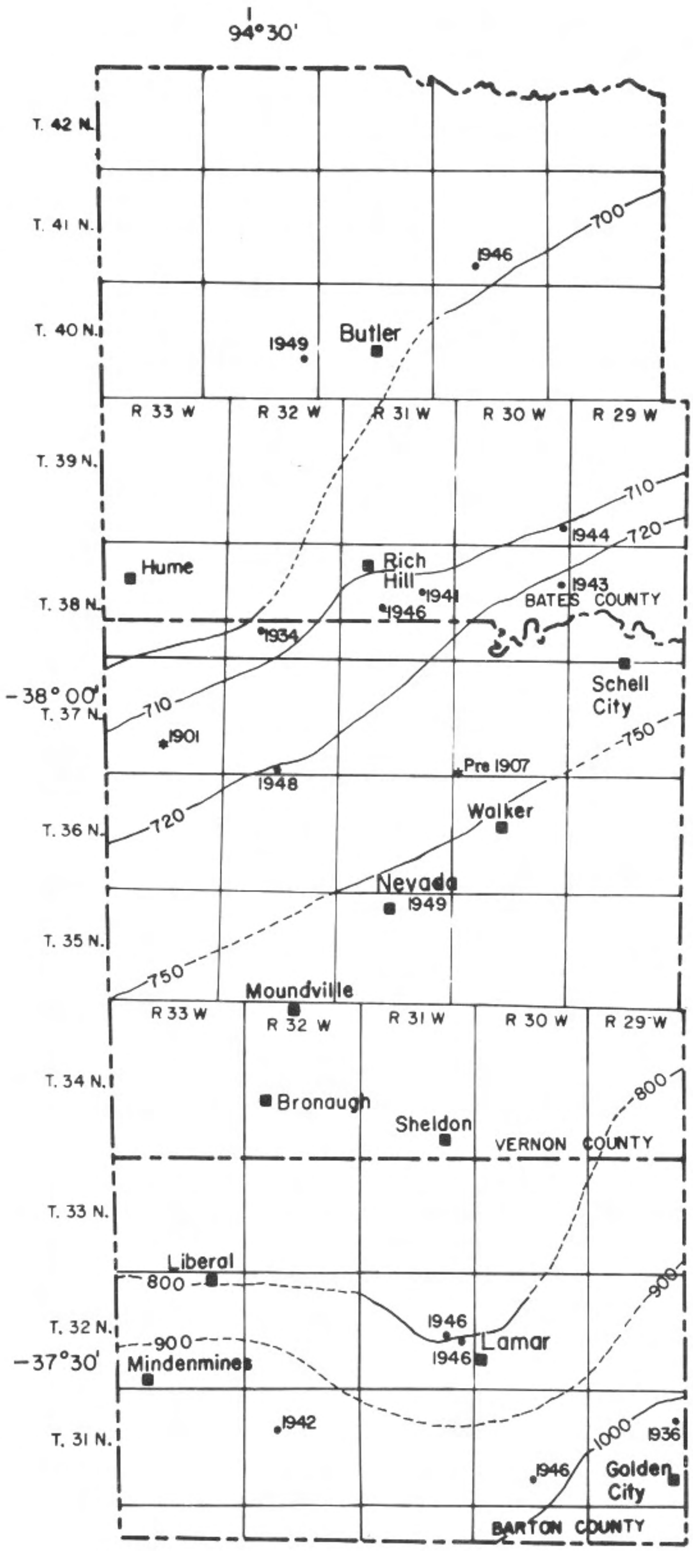
A generalized potentiometric map for the Mississippian aquifer was drawn from available historical data (fig. 16). A summary of the water-level data is given in Supplemental Data at the end of this report. The water levels represent the potentiometric surface in the study area before 1950. Because of few data points, little detail is shown, but a general northwestward trend of groundwater movement can be distinguished.

Shepard (1907) mentioned that two wells completed in the Mississippian aquifer in Vernon County were reported to have flowed. Greene and Pond (1926, p. 119) stated, "In some cases it seems probable that flowing water is encountered before reaching the Roubidoux, but the water is believed to come from that aquifer (Roubidoux), penetrating crevices in the overlying dolomite to the point at which it is encountered."

Based on wells open to the Mississippian aquifer, a map of the post-1950 potentiometric surface was also drawn for the study area (fig. 17). This map is similar to figure 16, in that the hydraulic-head gradient is shown to decrease northwestward. Comparison of the pre-1950 with the post-1950 potentiometric map shows that water levels in the Mississippian aquifer have declined approximately 10 ft in southeastern Bates County. A similar decline is shown where historical and recent water-level measurements were made in the same wells in Barton County. Although historical water-level measurements in northern Vernon County are scarce, a well producing from the Mississippian aquifer, east of Nevada, was measured during 1949 and again during 1982. The two measurements show a water-level decline of 42 ft, possibly caused by drawdown effects of withdrawals in the city's municipal-well field. A large concentration of irrigation wells less than 2 mi northwest of Nevada are open to both the Mississippian and Cambrian-Ordovician formations. Pumping from them may have caused some of the decline of water levels in the Mississippian aquifer in that vicinity.

Natural discharge of the Mississippian aquifer occurs as underflow of groundwater to adjacent areas. Artificial discharge is caused by withdrawals from wells in the area.

Because of lack of data in the study area, on long-term effects of large withdrawals from the Mississippian aquifer, it is necessary to consider data from elsewhere in the Tri-State Mining District to observe these effects. During 1932, C.F. Williams (Oklahoma Geological Survey) estimated that the Oklahoma-Kansas mining fields, the principal users of water from the Mississippian aquifer during the period, were pumping 13 million gallons per day (mgd) from the Osagean Series (Boone Forma-



EXPLANATION

1949 Well — Number is year water level was measured

Flowing Well — Reported by Shepard (1907)

—800-- Potentiometric Contour — Shows altitude at which water level would have stood in tightly cased wells. Dashed where approximately located. Contour interval, in feet, is variable. National Geodetic Vertical Datum of 1929

0 5 10 15 MILES
0 5 10 15 KILOMETERS

Figure 16 — Generalized altitude of the potentiometric surface of the Mississippian aquifer prior to 1950.

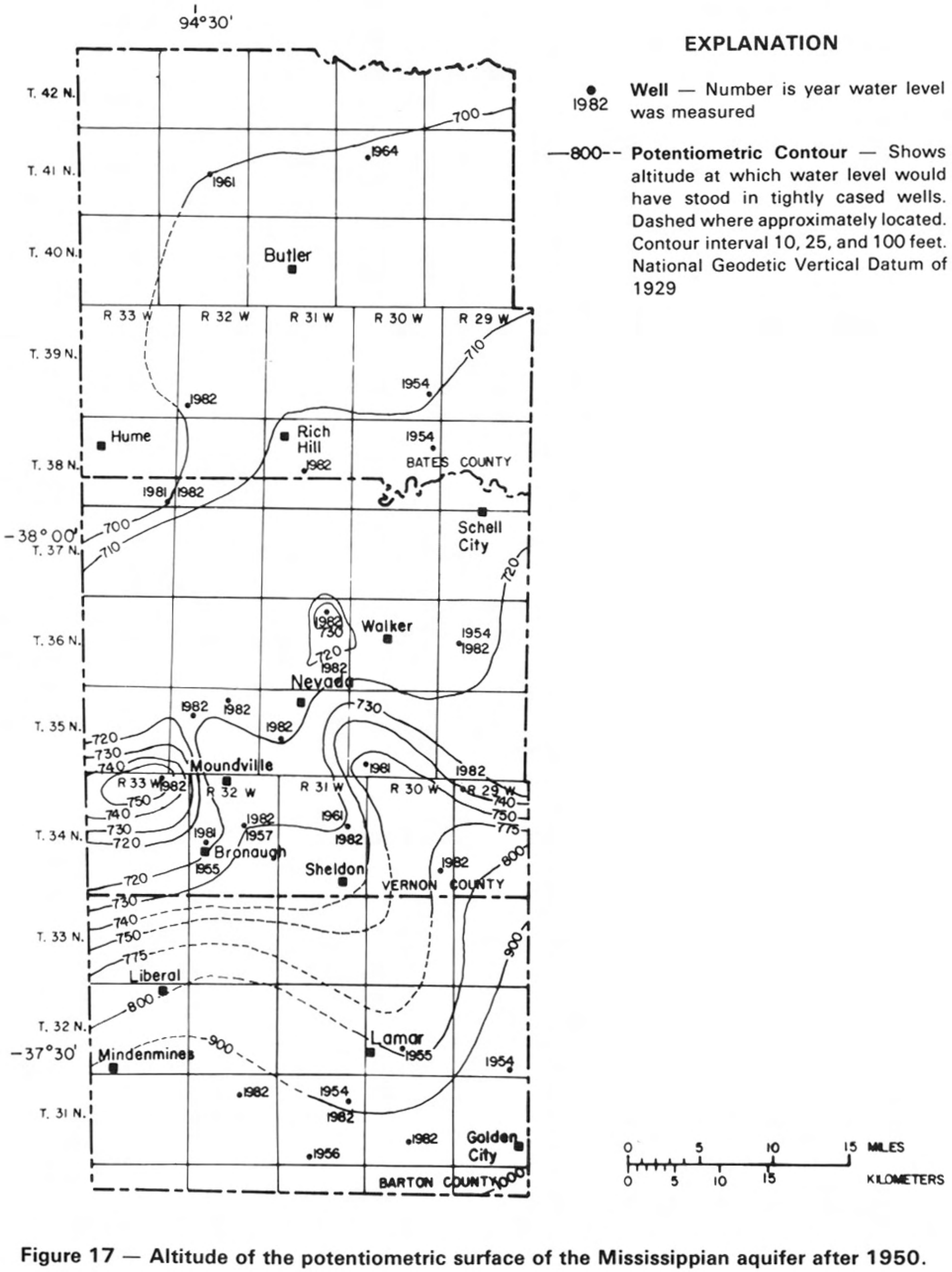


Figure 17 — Altitude of the potentiometric surface of the Mississippian aquifer after 1950.

tion in Oklahoma) for mine dewatering and general mining operations (Reed and others, 1955). In Ottawa County, Oklahoma, Mississippian rocks are exposed in four-fifths of the county, creating favorable conditions for groundwater recharge. According to Reed and others (1955, p. 85), "Despite this seemingly large discharge (from mining operations), ground water levels remain high in the Boone in Ottawa County except locally in the mining areas. Evidence of overdraft is lacking, and a condition of approximate equilibrium between recharge and discharge therefore may be assumed to exist."

The geology in southeastern Kansas differs from that in Ottawa County, Oklahoma, in the quantity and distribution of Mississippian and Pennsylvanian outcrops, but is similar to that in the study area. In both areas Pennsylvanian shales overlie the Mississippian aquifer, creating confined conditions. Abernathy (1941) reported on a prolonged aquifer test by the Eagle-Picher Mining and Smelting Company at its Garrett lease in Cherokee County, Kansas. At that site, 8 mgd were pumped from the Reeds Spring Formation for 7 months. The test indicated that although drawdown was great, water might be withdrawn at that rate without seriously depleting storage in the Reeds Spring.

During the early 1900's, apparently no regional lowering of Mississippian-aquifer water levels was caused by pumpage in the vicinity of the Oklahoma and Kansas mines, which are less than 40 mi from the study area. The general effect of large pumpage was local drawdown near the large-production well fields. With decrease of Tri-State mining operations during the 1950's, large-scale withdrawals from the Mississippian aquifer also decreased. During the middle 1960's, the practice of supplemental crop irrigation, using water from the Mississippian and Cambrian-Ordovician aquifers, increased in Barton and Vernon Counties. Large quantities of water are withdrawn during the irrigation season, but no regional water-level decline in the Mississippian aquifer is anticipated.

Cambrian-Ordovician Aquifer

The Cambrian-Ordovician aquifer in Barton, Vernon, and Bates Counties primarily is recharged from precipitation on the Salem Plateau of south-central Missouri (fig. 4) where Cambrian and Ordovician rocks are exposed. In southern Barton County, where the potentiometric surface of the Mississippian aquifer is higher than that of the Cambrian-Ordovician aquifer, it is possible that, where the Northview Formation forms a leaky confining layer, water moves downward from the Mississippian aquifer into the Cambrian-Ordovician aquifer.

In the Tri-State Mining District, historical data document water-level declines in wells open to the Cambrian-Ordovician aquifer in localized areas. In Ottawa County, Oklahoma, water levels in the Cambrian-Ordovician aquifer have declined as much as 400 ft (Reed and others, 1955, p. 94-95) since the late 1800's. In the Pittsburg, Kansas, municipal well field, the water-level declined 124 ft in the Cambrian-Ordovician aquifer between 1882 (when the first municipal well was drilled) and 1955. The city water superintendent estimated water use during this period averaged 1.4 mgd from the Cambrian-Ordovician aquifer (Stramel, 1957). Stramel (1957) used these data and transmissivity and storage coefficients obtained from eight aquifer tests at Pittsburg, Kansas, to calculate the expected drawdown in the area of Pittsburg well field. In the Theis nonequilibrium formula, 250,000 gpd/ft of aquifer thickness (33,000 ft^2/day) was used for transmissivity and 4.6×10^{-4} for the coefficient of storage, to calculate water-level declines caused by pumping the wells from 1882 to 1955. Using these coefficients, the calculated drawdown was 13.4 ft in the Pittsburg well field, but the measured drawdown for this period was 124 ft. The Theis curve and equations do not allow for leakage. Other aquifer tests in wells completed in the Cambrian-Ordovician aquifer, at the B.F. Goodrich Company at Miami, Oklahoma, and the Jayhawk Ordnance Plant 20 miles south of Pittsburg, indicated the transmissivity at these locations to be less than at Pittsburg. In explaining the discrepancy, Stramel concluded that Pittsburg is in a relatively small area where the aquifer is permeable and that there must be another discharge source. The drawdown was again calculated, this time for 50 years, and the transmissivity was decreased to 100,000 gpd/ft of aquifer thickness (13,000 ft^2/day. The resulting drawdown was calculated to be less than 12 ft at a distance of 2 mi. Stramel suggested that the large quantities of water withdrawn from the Boone Formation and Ordovician rocks during mining operations need to be considered when calculating water-level declines. Stramel concluded a hydraulic connection exists between the Mississippian and Ordovician aquifers in areas of the Tri-State region where the Chattanooga Shale is missing and where possibly no impervious beds exist (Stramel, 1957). It is not known if Stramel revised his transmissivity and water-use data, then duplicated the actual drawdown.

In northern Vernon County, the Northview Formation is relatively thin; it is possible that, at least locally, a hydraulic connection exists between the Mississippian and Cambrian-Ordovician aquifers. This possibility is supported by Greene and Pond (1926), who stated that flowing water encountered before reaching the Roubidoux Formation was believed to have come from the Cambrian-Ordovician aquifer, as in the two flowing wells completed in the Mississippian aquifer reported by Shepard (1907).

Another example of this occurred in a well drilled in northern Vernon County (sec. 8, T. 36 N., R. 31 W.) during 1922. Water began flowing at a depth of 270 ft, when the borehole was in Mississippian strata. Flow increased at a depth of 680 ft, when the well penetrated the Roubidoux Formation. No water sample was collected at 270 ft. After the well was completed, a water sample was collected, together with samples from two other deep wells in the same area. Analyses of the three samples indicated the characteristics of these waters to be similar and the water to be from the Roubidoux Formation (Greene and Pond, 1926).

Because of discrepancies in historical data and few data points, it is difficult to determine accurately the water-level decline in the study area. Most reported historical information concerns the Nevada area and northern Vernon County. Early reports, which record barometrically determined land-surface altitudes at well sites, contain several discrepancies between reported and true altitudes. In addition, the historical reports record no casing data for these wells, a circumstance making it impossible to confirm whether the recorded water levels represented only those in the Cambrian-Ordovician aquifer. According to Greene and Pond (1926, p. 119), however, reporting on flowing wells in Vernon County, "It seems probable that wells drilled to the Roubidoux Sandstone, if started on land not over 750 feet above sea level, will yield flowing water. In some places, wells are flowing or water stands in the well at an elevation of 800 feet or slightly higher."

Some historical data indicate that the potentiometric surface of the Cambrian-Ordovician aquifer in northern Vernon County was as much as 900 ft above sea level in the late 1800's. After correction of recorded land-surface altitudes of wells reported in the historical records, a revised potentiometric surface of 785 ft above sea level seems more consistent in northern Vernon County and indicates a water-level decline near Nevada of 80 ft since the early 1900's. Pre-1981 and current (1981-82) water-level data for wells completed in the Cambrian-Ordovician aquifer are summarized in Supplemental Data in this report. Potentiometric-surface maps for wells completed in the Cambrian-Ordovician aquifer for pre-1936, summer 1982, and fall 1982 are shown in figures 18, 19, and 20.

The 1982 potentiometric-surface maps (figs. 19 and 20), other than showing lowering of water levels, are consistent with the pre-1936 potentiometric-surface map (fig. 18). The pre-1950 potentiometric-surface map for the Mississippian aquifer and the pre-1936 map for the Cambrian-Ordovician aquifer (figs. 16 and 18) indicate that in northern Vernon County the Cambrian-Ordovician aquifer was discharging into the Mississippian aquifer. Most deep wells in the study area are open to both Mississippian and Cambrian-Ordovician aquifers; hence, the resulting water level is a composite of both systems. Comparison of water levels of wells open only to the Cambrian-Ordovician aquifer with those open to both aquifers generally indicated, however, that there was little difference in the potentiometric levels, even in that part of the study area where the two aquifers are separated by the Northview Formation. Discrepancies were such that they could be accounted for by accuracy in calculating land-surface altitudes, using topographic maps.

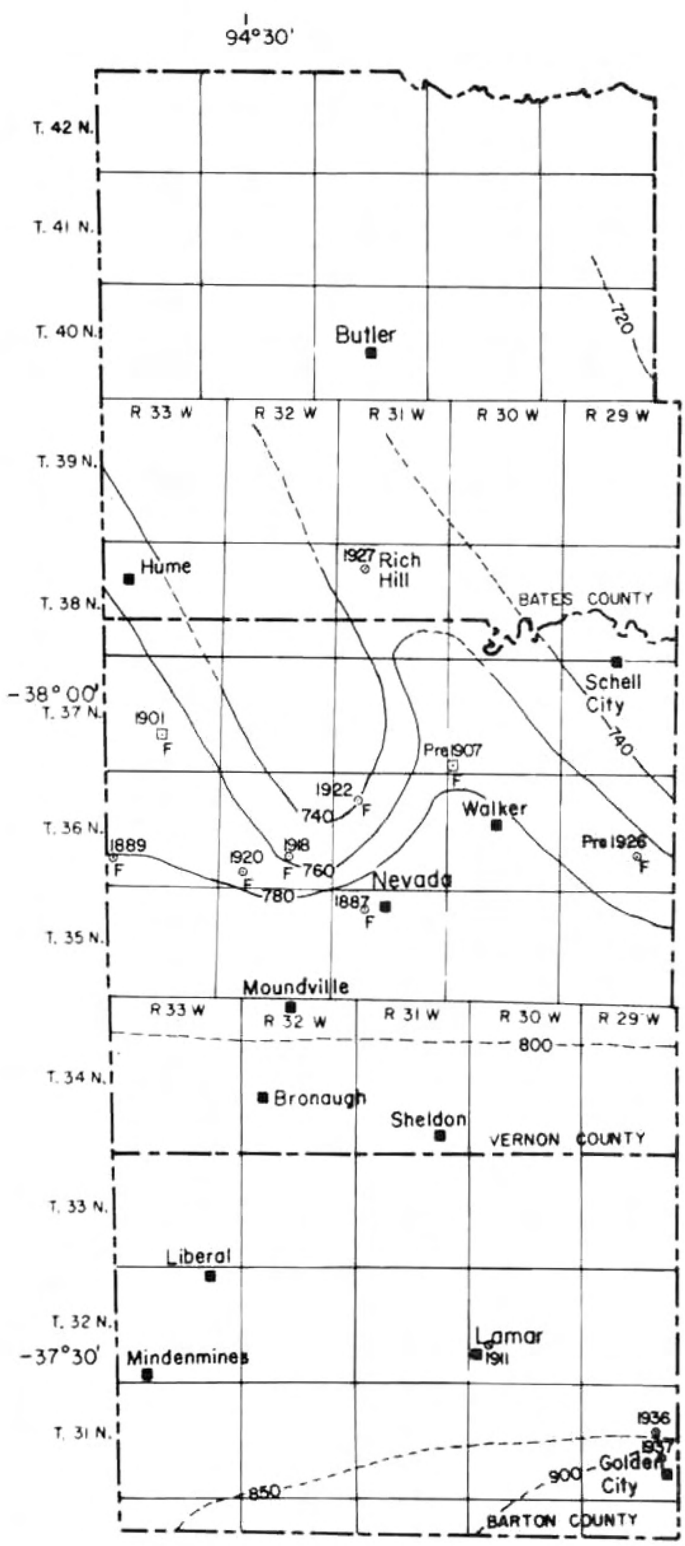
In southern Vernon County, the Northview Formation thickens to approximately 80 ft. With increasing thickness, water levels in the Mississippian and Cambrian-Ordovician aquifers gradually diverge. In southern Barton County the divergence is as much as 150 ft, (pl. 1) and the existence of two distinct aquifers becomes apparent.

In northern Vernon County, water-level altitudes in the Mississippian and the Cambrian-Ordovician aquifers converge because of natural and artificially created conditions. The Northview Formation is sufficiently thin to permit significant hydraulic connection between the two aquifers, causing hydraulic heads in both to be nearly equal. Many large-production wells in the area are also open to both aquifers, a condition allowing simultaneous pumpage from both.

In eastern Barton County, predevelopment and current (1982) potentiometric-surface maps of the Cambrian-Ordovician aquifer show a steep hydraulic gradient that flattens westward and northwestward. In Vernon County the even greater flattening of the gradient indicates increasing transmissivity. Macfarlane and others (1980) developed a map that shows transmissivities of the Cambrian-Ordovician aquifer across the Tri-State mining region. The map shows several large transmissivities in northern Vernon County.

The primary difference between summer and fall 1982 potentiometric-surface maps, is that depression cones around areas of intense pumpage are larger on the fall map, an expected result after a summer of increased groundwater use.

Natural discharge from the Cambrian-Ordovician aquifer occurs as groundwater movement into adjoining



EXPLANATION

1887 F — **Well Completed in Cambrian-Ordovician Aquifer** — Number is year of measurement. F, indicates flowing well, as reported by Greene and Pond (1926)

Pre1907 F — **Well Completed in Mississippian Aquifer Believed to Yield Water from Cambrian-Ordovician Aquifer** — Number is year of measurement. F, indicates flowing well, as reported by Shepard (1907)

—780-- **Potentiometric Contour** — Shows altitude at which water-level would have stood in tightly cased wells. Dashed where approximately located. Contour intervals 20 and 50 feet. National Geodetic Vertical Datum of 1929

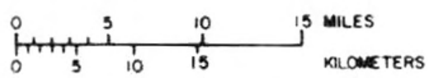
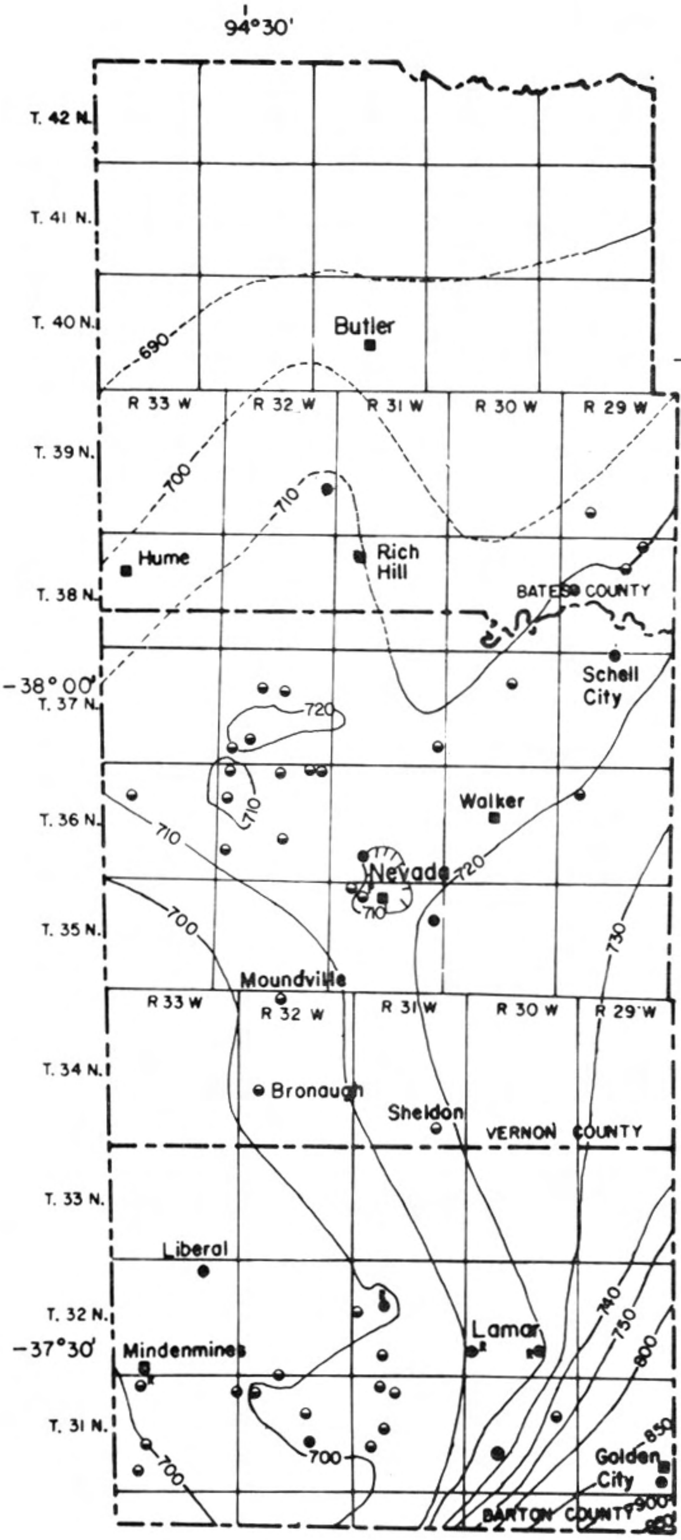


Figure 18 — Altitude of the potentiometric surface of the Cambrian-Ordovician aquifer before 1936.



EXPLANATION

Well Open to Mississippian and Cambrian-Ordovician Aquifers — Potentiometric surface is similar to that of Cambrian-Ordovician aquifer in study area

Well Open to Cambrian-Ordovician Aquifer

—720-- **Potentiometric Contour** — Shows altitude at which water level would have stood in tightly cased wells. Dashed where approximately located. Contour interval 10 and 50 feet. National Geodetic Vertical Datum of 1929

P/R **Well Status During Measurement** — P, indicates pumping; R, recently pumped

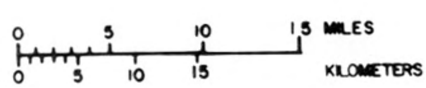


Figure 19 — Altitude of the potentiometric surface of the Cambrian-Ordovician aquifer, summer 1982.

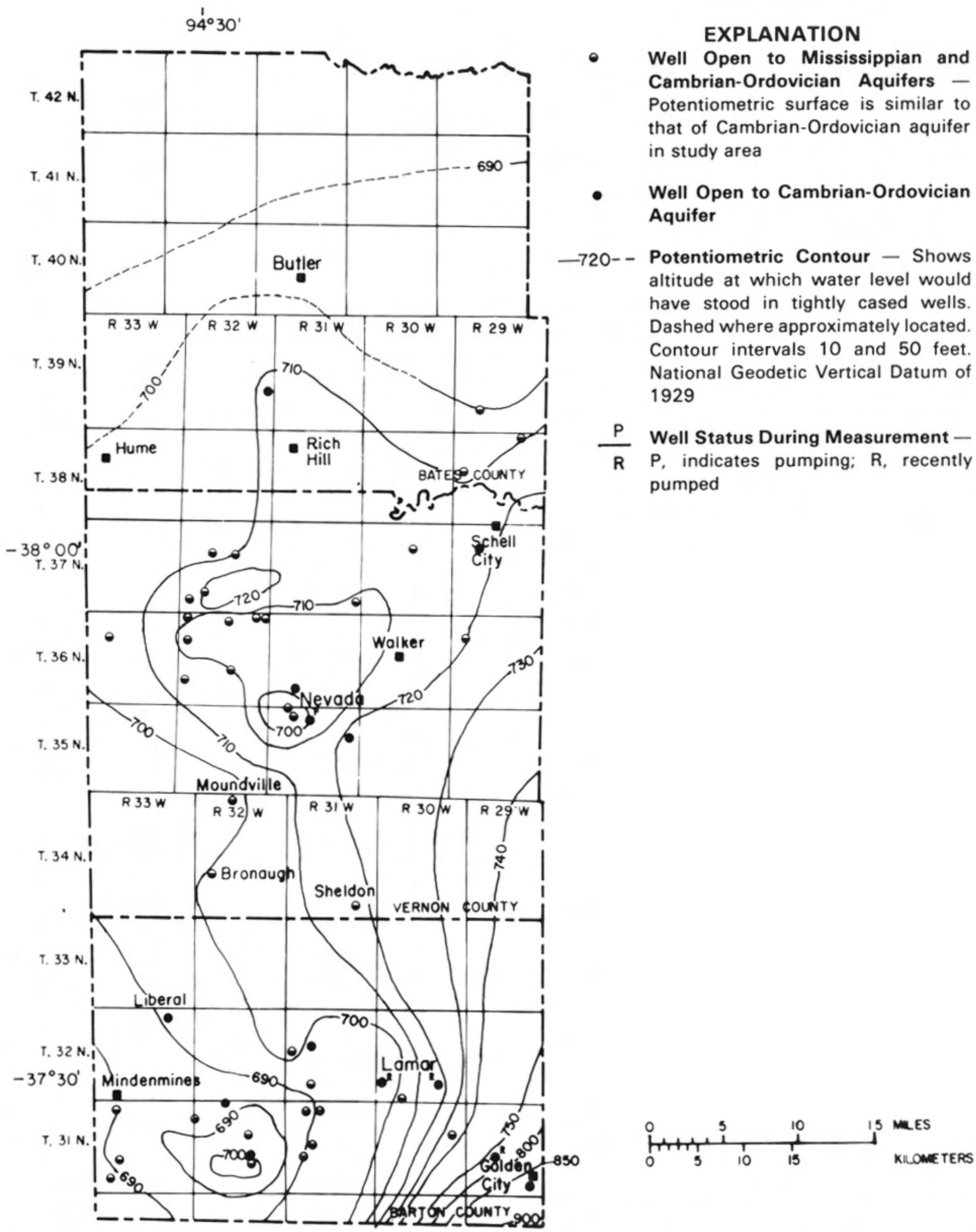


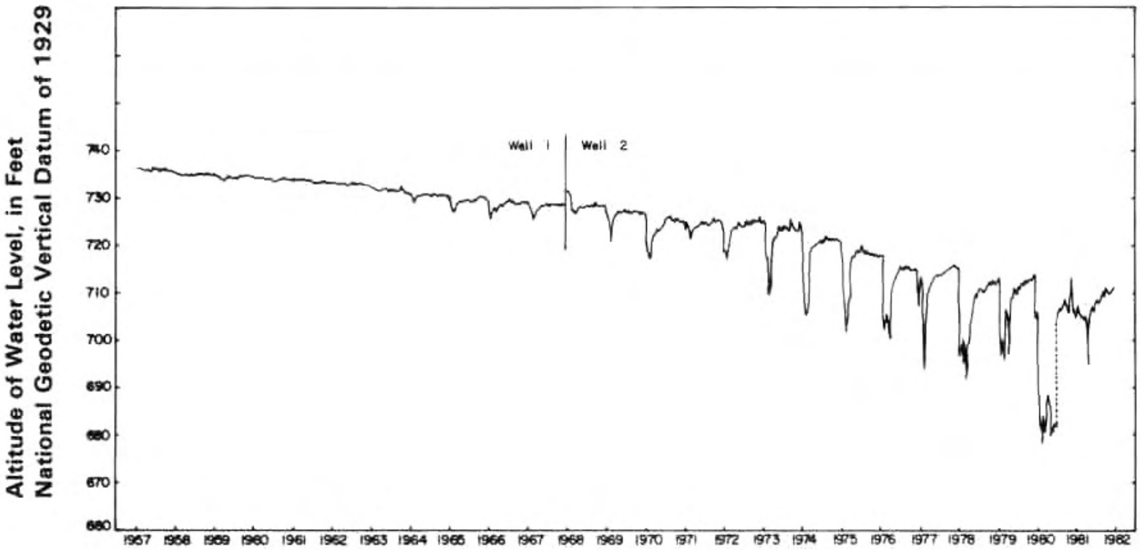
Figure 20 — Altitude of the potentiometric surface of the Cambrian-Ordovician aquifer, fall 1982.

areas of Kansas, and as water ascending into the overlying Mississippian aquifer where a confining bed is absent. Artificial discharge occurs as withdrawals for municipal, irrigation, and industrial use. Several large municipal well fields can be identified by their cones of depression.

In areas where the Northview Formation separates Mississippian and Cambrian-Ordovician aquifers hydraulically and where the shale in the Pennsylvanian aquifer covering the area has little permeability to hinder groundwater movement, local precipitation on the aquifer has little effect. Water-level data from the city of Lamar, well 1, show that water levels in this well fluctuate very little, a condition indicating that the Ordovician System is buffered from local climatic conditions (fig. 21) in that area. Little or no seasonal fluctuation occurred from 1957 to 1964.

At Lamar, water-level fluctuations in an observation well operated by the Missouri Division of Geology and Land Survey show the general trend of the water-level decline in the Cambrian-Ordovician aquifer (fig. 21). A continuous water-level recorder installed in Lamar well 1 in July 1957 remained at this location until June 1968, when it was moved approximately 1 mi north to Lamar well 2. Both wells have similar construction (table 3).

During July 1957 through July 1964, there was normal cumulative precipitation in the area (fig. 22), but a gradual water-level decline is discernible (fig. 21), indicating that discharge exceeded recharge to the aquifer and that there was a net decrease in storage. For those 7 years, the total water-level decline was 5.3 ft, or an annual average of 0.75 ft. Before 1964 there was one irrigation system, one railroad line, and three municipalities (Liberal, Mindenmines, and Golden City) known to be using large-production wells drilled into the Cambrian-Ordovician aquifer in Barton County. Of these, the two nearest the Lamar observation wells are the irrigation well and the Golden City municipal



Hydrograph data from Missouri Division of Geology and Land Survey

Figure 21 — Water-level fluctuations in Lamar's city wells, completed in the Cambrian-Ordovician aquifer, 1957-82.

TABLE 3

Construction data for observation wells completed in the Cambrian-Ordovician aquifer at Lamar
(Data from Missouri Division of Geology and Land Survey)

	Well 1	Well 2
Location	T. 32 N., R. 30 W., sec. 31bab	T. 32 N., R. 30 W., sec. 30abb
Land surface altitude	955 ft above sea level	980 ft above sea level
Total depth	971 ft	981 ft
Casing data	553 ft of 8-in. diameter	575 ft of 8-in. diameter
Date recorder installed	July 1957	June 17, 1968
Formations open to well	Cotter-upper Gasconade Dolomites	Cotter-upper Gasconade Dolomites

well, about 6 and 12 mi away, respectively. Interference effects from these on the observation well would probably be negligible, based on these distances and the quantities of water they produce. The observation well is located where geologic conditions are representative of much of the study area; water-level fluctuations in the well are believed to show areal, not just local trends.

No drawdown interference is expected from the city of Lamar. In 1955 Lamar changed to a surface-water impoundment as a municipal water source, and the wells have subsequently been unused. The only expected interference is when the pumps are operated briefly each month for routine maintenance checks (J.A. Roberts, Lamar City Superintendent, oral commun., 1982).

Before 1964 the two largest users of water from the Cambrian-Ordovician aquifer in the area were Pittsburg, Kansas, and Nevada, Missouri. Since 1964 production from the Cambrian-Ordovician aquifer near the Lamar observation well has greatly increased. During the mid-1960's, supplemental crop irrigation increased substantially in the vicinity. In 1967 several public water-supply wells came into production, and in 1970 the city of Lamar allowed a local industry to begin using well 1 for water supply.

During 1964 the Lamar observation-well hydrograph (fig. 21) began showing effects of local pumping, as indicated by a slight seasonal drawdown at the end of July and into August. As production from the Cambrian-Ordovician wells increased during the years, so did the seasonal drawdown; during 1964 it was 1.5 ft. Drawdown has increased gradually; during the drought of 1980, a maximum observed drawdown of 35.5 ft was recorded.

The peak demand for groundwater from wells directly affecting the observation well occurs from early summer until late fall; normal use occurs during winter and spring. The industry in Lamar currently using the only large-production, deep well in the city, well 1, uses a relatively constant quantity of water most of the year (Carolyn Taffner, City Clerk, Lamar, oral commun., 1982). However, the industry does have a large-production period from September through November (Ralph Williston, manufacturing-plant chemist, Lamar, oral commun., 1982). It is assumed the public water-supply wells reach their peak demand during the summer. The operational period for irrigation systems is generally between June and October, depending on crop types and local precipitation.

For 1964 through 1981, the cumulative precipitation departure from

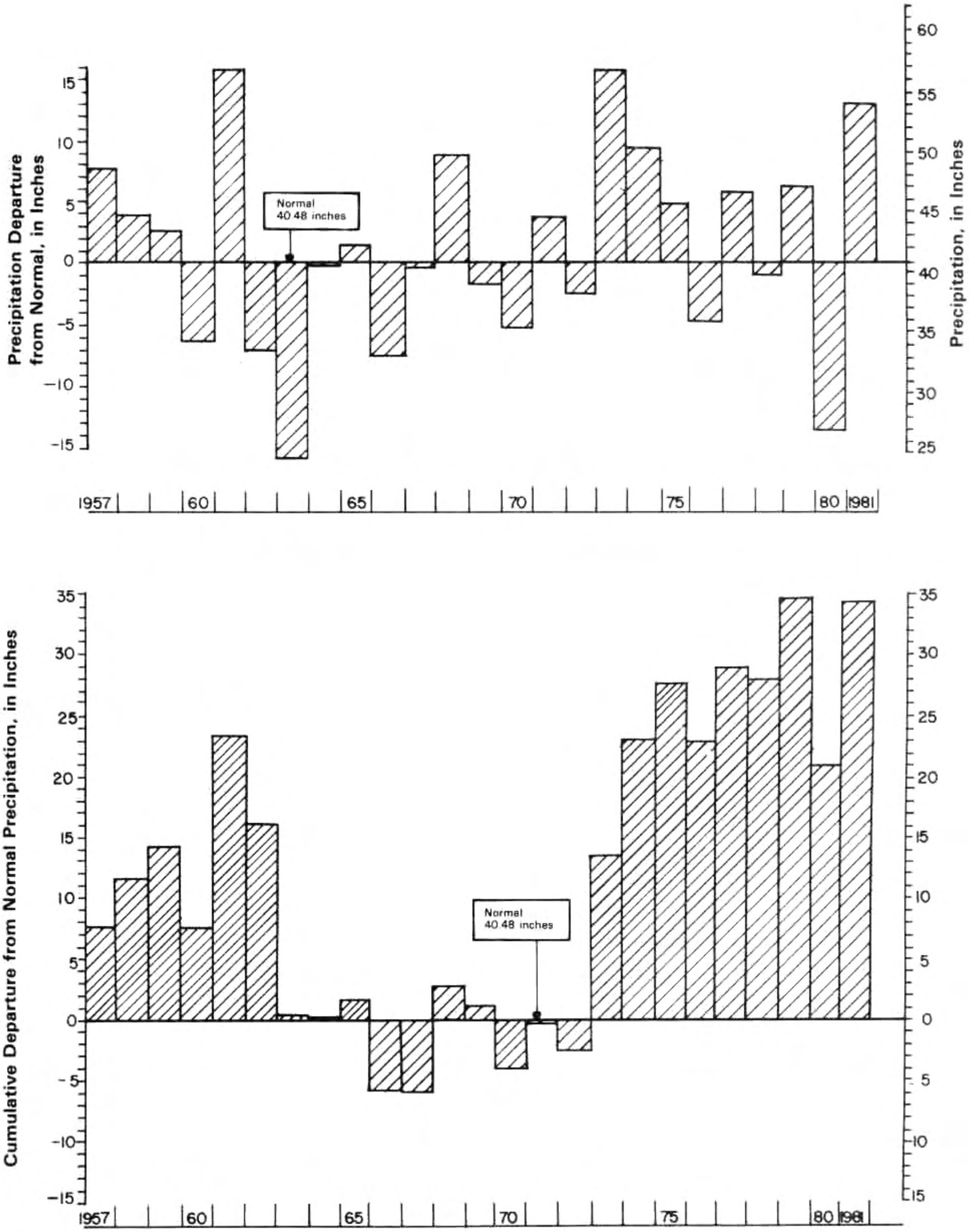


Figure 22 — Departure from normal precipitation at Lamar, 1957-81.

normal, 34.01 in. greater than normal (fig. 22), indicates that declining water levels cannot be attributed to lack of precipitation. Recharge to the aquifer system and decreased demands during winter and spring allow the water level to recover partially, but an annual net decline still occurs. Since 1964 the potentiometric surface of the Cambrian-Ordovician aquifer at Lamar has declined approximately 23 ft and the average yearly decline has increased to 1.3 ft. It is assumed that increased production from this aquifer will cause increased water-level declines.

Groundwater Quality

Groundwater quality varies in the study area. Concentrations of dissolved solids in water generally increase northwestward. Swenson and Baldwin (1965) classified the degree of salinity of water as follows:

Dissolved-solids concentration, in milligrams per liter	Degree of salinity
Less than 1,000	Nonsaline
1,000 to 3,000	Slightly saline
3,000 to 10,000	Moderately saline
10,000 to 35,000	Very saline
More than 35,000	Brine

According to available data, groundwater is nonsaline in the southeastern part of the study area and moderately saline in the northwestern part.

Pennsylvanian Aquifer

Water-quality data are sparse for the Pennsylvanian aquifer. In the eastern part of the study area the aquifer is thin and not readily usable for water supplies; in the western part, water quality may be affected by extensive oil production (Darr, 1978, p. 34). No wells completed in the Pennsylvanian aquifer were sampled for this study, but existing data are shown in figure 23.

Of the 10 analyses available, dissolved-solids concentrations were less than 1000 mg/l in two samples and greater than 3000 mg/l in seven. Sufficient data to show the areal distribution of dissolved-solids concentrations are unavailable. Sodium and chloride are the predominant ions in water in the Pennsylvanian aquifer.

Mississippian Aquifer

Water samples were collected by the U.S. Geological Survey from 18 wells completed in the Mississippian aquifer during July-September 1982 (table 4). Chemical analyses show that the water had concentrations of dissolved solids ranging from 318 mg/l in Vernon County to 4150 mg/l in Bates County. Chloride concentrations ranged from 7.9 mg/l in Vernon County to 2300 mg/l in Bates County.

Data from Darr (1978) were combined with the 1982 data to prepare figure 24. Concentrations of dissolved solids and water type vary areally. The general trend of dissolved-solids concentrations shows an increase from 318 mg/l in a sodium bicarbonate-type water, in southeast Vernon County, to 7315 mg/l in a sodium chloride-type, in northern Bates County. In the study area, water can be classified as nonsaline to at least moderately saline. Calcium-to-magnesium ratios for water from wells completed in the Mississippian aquifer were calculated from the data in table 4 and expressed in milliequivalents per liter (meq/l). So expressed, ratios varied from 0.70 to 2.5 in all samples but one, which was 22.5. Barks (1977) tabulated average concentrations of calcium and magnesium in water from Mississippian wells in the Joplin area; the average calcium-to-magnesium ratio calculated from his data is about 7.0. Harvey (1980) stated that the ratio from limestone rocks in the Springfield-Salem

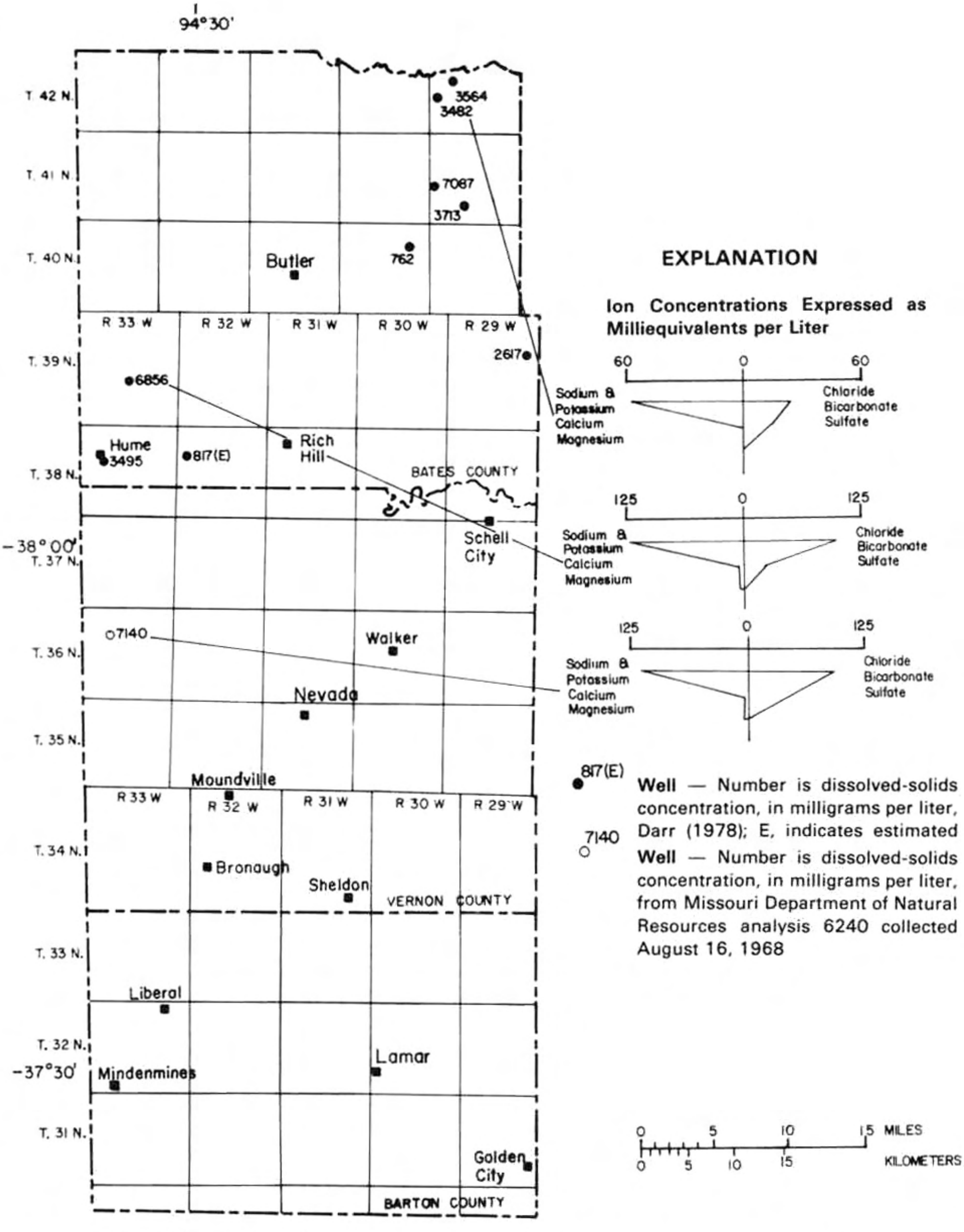


Figure 23 — Dissolved-solids concentrations and stiff diagrams for water samples from the Pennsylvanian aquifer.

TABLE 4

Water-quality data for wells in Barton, Vernon, and Bates Counties, 1982

(µmhos, micromhos per centimeter at 25° Celsius; ° C, degrees Celsius; mg/l, milligrams per liter; <, less than)

Well number	Location	Date of sample	Specific conductance (µmhos)	pH (units)	Temperature (° C)	Calcium, dissolved (mg/l as Ca)	Magnesium, dissolved (mg/l as Mg)	Sodium, dissolved (mg/l as Na)	Sodium adsorption ratio	Potassium, dissolved (mg/l as K)	Bicarbonate (mg/l as HCO_3)	Sulfate, dissolved (mg/l as SO_4)	Chloride, dissolved (mg/l as Cl)	Solids residue at 180° C dissolved (mg/l)
						Barton County								
1	T. 31 N., R. 29 W., 20aab1[2]	82-7-21	280	8.0	19.5	32	14	3.3	0.1	1.2	162	11	2.7	147
2	T. 31 N., R. 29 W., 35bbb1[2]	82-7-20	268	8.0	20.0	29	14	2.4	.1	1.6	156	11	1.9	144
3	T. 31 N., R. 30 W., 11ddb1[2]	82-7-20	326	7.8	20.0	37	19	3.6	.1	1.2	196	10	2.3	175
4	T. 31 N., R. 31 W., 4cac2[2]	82-7-21	358	7.8	21.0	34	16	15	.6	2.6	195	13	16	196
5	T. 31 N., R. 31 W., 17daa1[2]	82-7-21	364	8.3	21.0	35	16	16	.6	2.7	195	14	15	201
6	T. 31 N., R. 31 W., 20abc1[2]	82-7-21	423	7.9	22.0	37	17	24	.9	2.9	195	16	29	226
7	T. 31 N., R. 32 W., 6cbc1[2]	82-9-23	705	7.9	20.0	39	17	90	3.3	4.1	358	24	53	363
8	T. 31 N., R. 32 W., 10dbb1[2]	82-7-21	590	7.8	23.0	44	20	53	1.8	3.8	232	21	65	314
9	T. 31 N., R. 32 W., 21ccb1[2]	82-7-21	609	7.7	21.0	44	20	50	1.6	4.1	224	22	71	334
10	T. 31 N., R. 32 W., 22aaa1[2]	82-7-22	595	7.7	22.0	42	19	47	1.7	3.7	226	21	69	320
11	T. 31 N., R. 32 W., 22adc1[2]	82-9-24	547	7.5	20.5	41	19	43	1.5	3.8	216	21	60	267
12	T. 31 N., R. 33 W., 5bbc1[2]	82-7-22	683	7.6	22.0	40	17	86	3.1	3.8	334	22	55	381
13	T. 32 N., R. 30 W., 27aad1[2]	82-7-22	290	8.0	20.0	31	15	5.1	.2	1.6	172	11	3.4	153
14	T. 32 N., R. 30 W., 31bab1[2]	82-7-21	323	7.9	20.5	35	16	7.6	.3	2.3	196	12	4.8	179
15	T. 32 N., R. 30 W., 32acc1[2]	82-7-21	323	7.9	20.0	34	17	6.9	.3	2.0	196	12	5.2	172
16	T. 32 N., R. 31 W., 17aaa1[2]	82-7-22	400	7.9	21.0	34	16	25	1.0	2.5	192	13	27	214
17	T. 32 N., R. 31 W., 18caa1[2]	82-9-23	510	8.2	20.0	36	17	44	1.7	3.5	206	18	62	267
18	T. 32 N., R. 31 W., 28cac1[2]	82-7-20	425	7.8	22.0	34	15	31	1.2	3.0	206	13	26	230
19	T. 32 N., R. 33 W., 2acd2[2]	82-7-222	763	7.7	21.0	45	21	83	2.8	4.5	248	25	110	405
						Vernon County								
20	T. 34 N., R. 29 W., 6aaa1[1]	82-9-23	595	7.6	17.0	37	20	67	2.4	5.8	318	44	16	318
21	T. 34 N., R. 30 W., 25bcd1[1]	82-7-23	942	7.5	17.0	85	44	56	1.4	5.0	317	250	7.9	629
22	T. 34 N., R. 31 W., 11ada1[1]	82-7-30	1,400	7.9	17.5	6.6	2.8	340	31	5.8	806	5.0	83	852
23	T. 34 N., R. 31 W., 35ada3[2]	82-7-23	810	7.8	20.0	42	18	97	3.4	4.1	218	22	150	435
24	T. 34 N., R. 32 W., 5aaa1[2]	82-9-22	1,970	7.8	18.5	39	19	390	13	8.6	746	40	290	1,070
25	T. 34 N., R. 32 W., 20baa1[2]	82-7-22	2,080	7.5	21.0	75	33	310	7.5	9.0	324	69	510	1,160
26	T. 35 N., R. 30 W., 32bab1[1]	82-7-30	990	8.0	18.0	8.4	4.2	260	20	5.8	630	20	62	683
27	T. 35 N., R. 31 W., 5dba1[2]	82-7-29	2,270	7.5	20.0	77	38	330	7.7	9.8	274	75	580	1,310
28	T. 35 N., R. 31 W., 13abc1[2]	82-7-30	1,775	7.6	19.0	61	31	250	7.2	8.0	260	54	430	1,020
29	T. 35 N., R. 31 W., 20bdc1[1]	82-9-23	1,240	7.9	16.0	0.4	0.1	330	129	.9	754	<5.0	58	774
30	T. 35 N., R. 32 W., 17acb1[1]	82-7-29	2,300	7.6	18.5	12	9.8	550	29	9.4	1,158	17	220	1,410
31	T. 36 N., R. 29 W., 7dbd1[2]	82-7-28	1,200	7.6	20.0	53	24	160	5.0	6.6	226	35	260	606
32	T. 36 N., R. 29 W., 9baa1[2]	82-7-28	1,105	7.6	18.0	50	24	140	4.5	6.1	226	34	230	594
33	T. 36 N., R. 29 W., 17cdd1[1]	82-7-28	1,110	7.6	20.0	44	22	140	4.7	6.3	238	28	230	590
34	T. 36 N., R. 30 W., 15bcc1[2]	82-7-28	1,350	7.6	20.0	57	27	210	6.3	7.5	242	41	340	816
35	T. 36 N., R. 31 W., 33bcb1[2]	82-7-29	2,300	7.4	19.5	81	40	330	7.5	10	270	73	580	1,330
36	T. 36 N., R. 31 W., 36cba1[1]	82-7-27	1,650	7.6	21.5	.9	.0	430	123	2.5	814	<5.0	180	1,030
37	T. 36 N., R. 32 W., 1aca1[2]	82-7-27	2,150	7.8	19.5	82	39	360	8.2	11	276	71	640	1,370
38	T. 36 N., R. 32 W., 3caa1[2]	82-7-27	2,340	7.5	19.0	76	36	360	8.5	11	308	68	600	1,320
39	T. 36 N., R. 32 W., 4cca1[2]	82-7-26	2,225	7.4	19.5	77	37	370	8.7	11	298	74	660	1,410

TABLE 4 (cont.)

Well number	Location	Date of sample	Specific conductance (μmhos)	pH (units)	Temperature (° C)	Calcium, dissolved (mg/l as Ca)	Magnesium, dissolved (mg/l as Mg)	Sodium, dissolved (mg/l as Na)	Sodium adsorption ratio	Potassium, dissolved (mg/l as K)	Bicarbonate (mg/l as HCO_3)	Sulfate, dissolved (mg/l as SO_4)	Chloride, dissolved (mg/l as Cl)	Solids residue at 180° C dissolved (mg/l)
					Vernon County (cont.)									
40	T. 36 N., R. 32 W., 7dbd1[2]	82-7-27	2,340	7.5	19.5	82	39	380	8.7	12	290	76	690	1,460
41	T. 36 N., R. 32 W., 22dbc1[2]	82-7-27	2,125	7.8	20.0	74	36	350	8.3	11	294	68	600	1,310
42	T. 36 N., R. 32 W., 30aca1[2]	82-7-27	3,150	7.2	18.5	55	30	610	16	13	774	36	750	1,800
43	T. 37 N., R. 29 W., 8dcb1[2]	82-7-27	1,430	7.7	20.5	50	24	200	6.4	7.5	246	39	320	784
44	T. 37 N., R. 30 W., 10cdc1[2]	82-7-27	1,730	7.9	21.0	–	–	–	–	–	268	–	–	–
45	T. 37 N., R. 30 W., 23dda1[1]	82-7-28	2,190	6.7	17.5	150	89	230	3.7	11	348	720	200	1,670
46	T. 37 N., R. 31 W., 17dbd1[2]	82-7-26	2,440	7.4	19.0	76	37	370	8.7	11	274	75	620	1,400
47	T. 37 N., R. 31 W., 36abd1[2]	82-7-27	1,840	7.5	21.0	69	34	300	7.4	9.6	286	62	520	1,150
48	T. 37 N., R. 32 W., 15aac1[2]	82-7-26	2,590	7.4	19.5	87	41	400	8.9	12	288	74	720	1,510
49	T. 37 N., R. 32 W., 16bad1[2]	82-7-26	2,650	7.4	20.0	85	41	410	9.1	12	288	78	750	1,540
50	T. 37 N., R. 32 W., 32bac1[2]	82-7-21	2,430	7.4	19.5	86	41	420	9.3	12	300	78	740	1,560
51	T. 38 N., R. 29 W., 33ddd1[2]	82-7-28	1,510	7.5	19.0	53	25	220	6.9	7.8	242	37	340	797
52	T. 38 N., R. 32 W., 29aad1[1]	82-7-28	2,850	7.5	20.5	64	35	490	12	12	344	77	780	1,620
					Bates County									
53	T. 38 N., R. 29 W., 18ccd1[1]	82-9-22	2,330	7.7	16.5	58	31	380	10	11	270	53	610	1,230
54	T. 38 N., R. 30 W., 3dad1[1]	82-9-22	2,100	7.5	17.5	62	33	340	8.7	9.6	340	98	470	1,110
55	T. 38 N., R. 31 W., 8acb1[2]	82-9-22	3,375	7.3	18.0	92	43	580	13	13	294	85	1,000	1,880
56	T. 38 N., R. 31 W., 18dba1[1]	82-9-22	2,570	7.8	18.0	60	29	480	13	11	512	61	610	1,450
57	T. 38 N., R. 31 W., 20cdb1[1]	82-9-22	1,390	8.3	16.0	9.5	4.4	340	25	7.2	908	8.0	52	875
58	T. 38 N., R. 32 W., 16dcc1[1]	82-9-21	3,525	7.5	19.0	81	40	600	14	13	382	80	1,000	1,850
59	T. 39 N., R. 29 W., 29ccd1[2]	82-9-22	3,900	7.5	18.5	89	42	700	15	14	300	84	1,200	2,160
60	T. 39 N., R. 32 W., 31aba1[1]	82-9-21	7,500	8.1	16.0	42	22	1,600	50	21	736	28	2,300	4,150
61	T. 39 N., R. 33 W., 15bcc1[1]	82-9-21	5,000	8.0	16.0	17	14	1,200	52	10	1,300	16	1,200	2,960
62	T. 41 N., R. 32 W., 15ccd1[3]	82-9-21	820	7.8	21.0	60	30	76	2.2	1.6	368	110	13	440

[1]Well primarily open to the Mississippian aquifer

[2]Well primarily open to the Cambrian-Ordovician aquifer

[3]Sample was treated before collection and is not discussed in text or maps

Plateau ". . . is more than 1.0 and ranges as high as 10.0 or more." No explanations can be made for the small calcium-to-magnesium ratios in water from the Mississippian aquifer.

Cambrian-Ordovician Aquifer

Forty-four wells completed in the Cambrian-Ordovician aquifer were sampled by the U.S. Geological Survey during July-September 1982 (table 4). Because of large dissolved-solids concentrations, only two wells were available for sampling in Bates County. Concentrations of dissolved solids ranged from 144 mg/l in Barton County to 2160 mg/l in southeastern Bates County. Chloride concentrations ranged from 1.9 mg/l in Barton County to 1200 mg/l in Bates County.

Distribution of dissolved-solids concentrations for 1982 (fig. 25) is similar

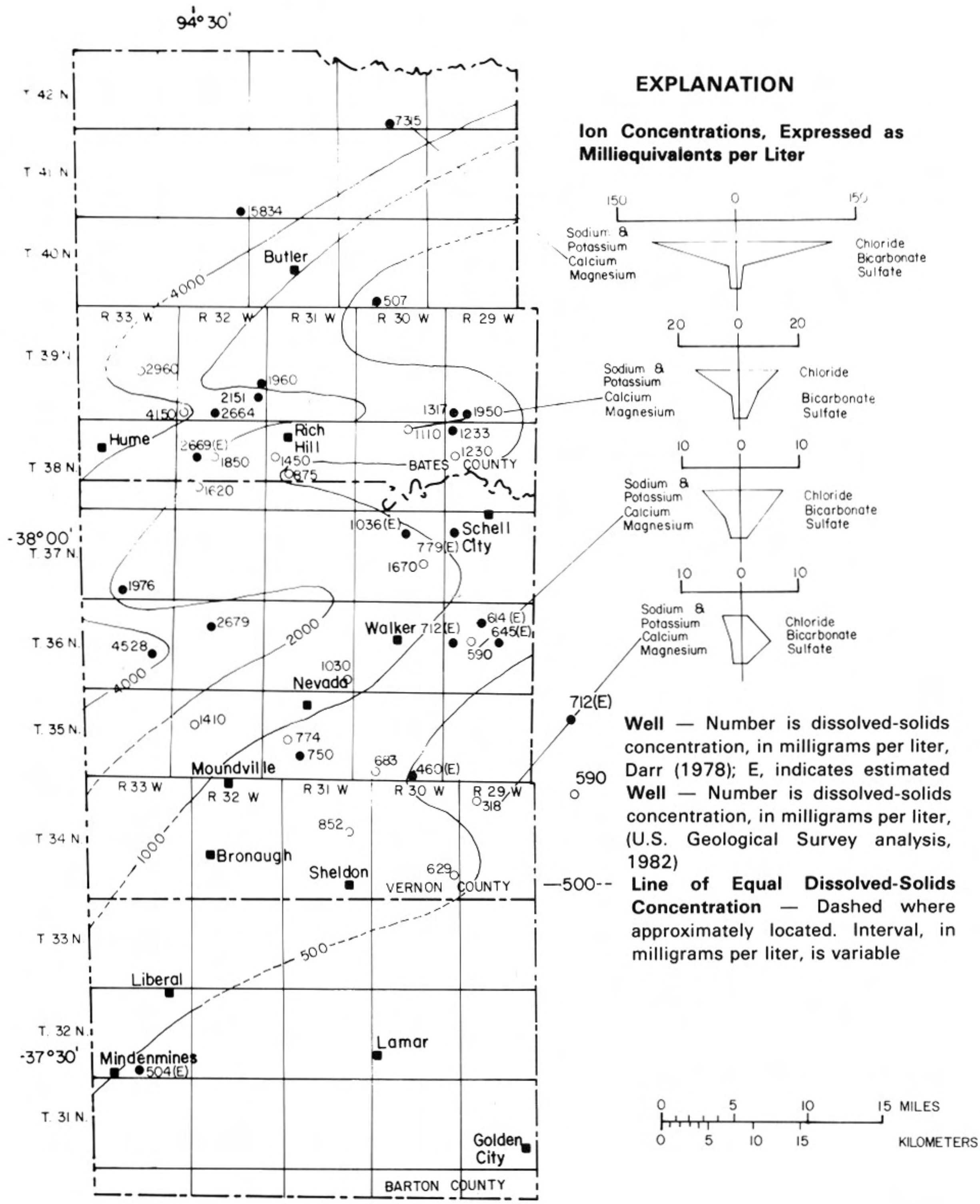


Figure 24 — Dissolved-solids concentrations and stiff diagrams for water samples from the Mississippian aquifer.

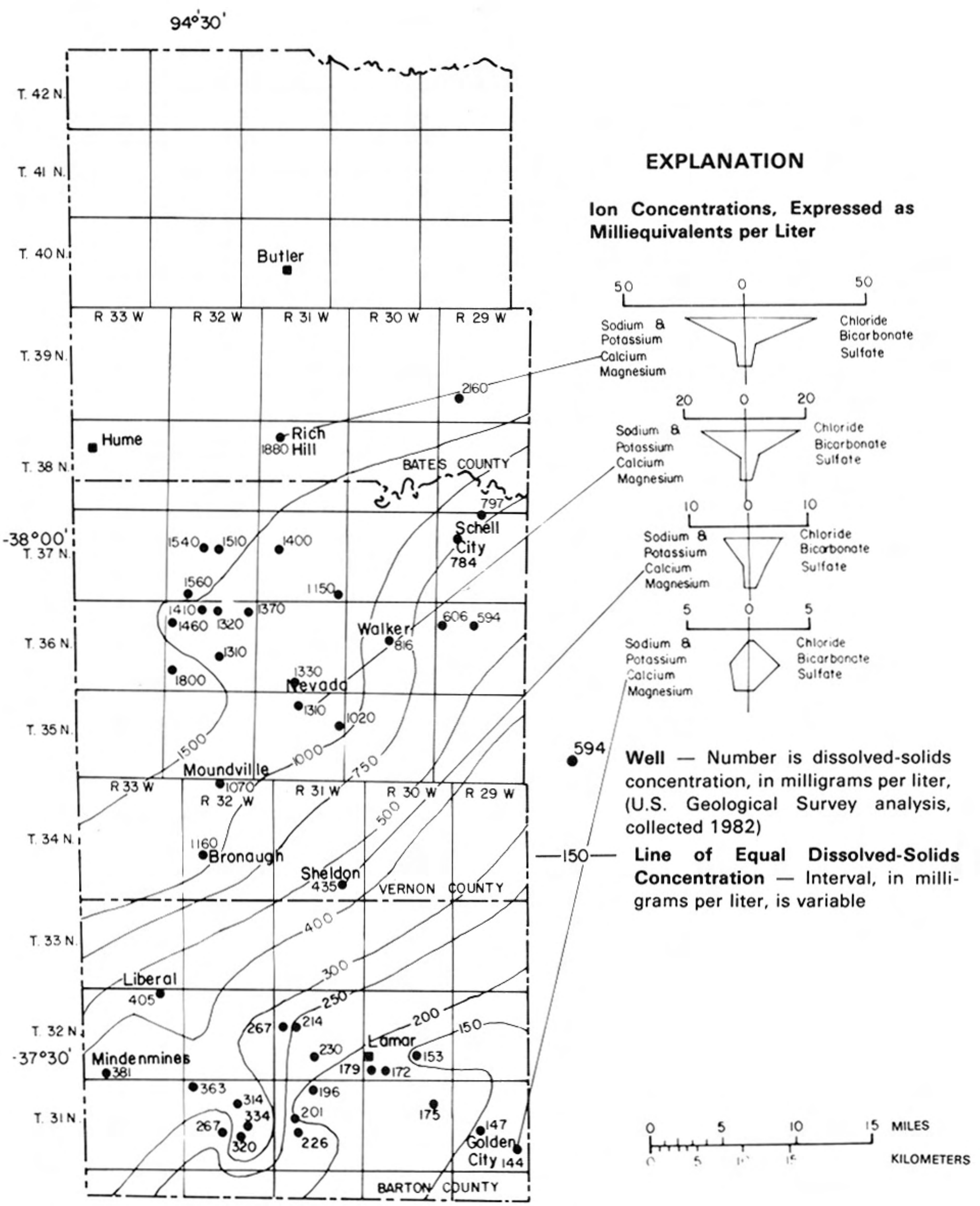


Figure 25 — Dissolved-solids concentrations and stiff diagrams for water samples from the Cambrian-Ordovician aquifer.

to that shown by Darr (1978), Frick (1980), and Macfarlane and others (1980). The position of the 1000-mg/l line appears to approximate that shown by those authors. It is therefore concluded that the freshwater-saline-water boundary has not moved substantially in recent years, but that only minor fluctuations occur along the boundary zone.

Historical water-quality data were compared to 1982 analyses (fig. 26) to determine changes in water quality in public-supply wells in the study area. Public-supply wells at Golden City have continued to produce a calcium magnesium bicarbonate-type water; water from wells at Liberal and Mindenmines, however, has changed from predominantly sodium bicarbonate-type, with a large dissolved-solids concentration, to a mixed type, with decreased dissolved-solids concentration but increased chloride concentration. Water from public supplies in Vernon County show the most change in primary constituents, but dissolved-solids concentration remains relatively constant. Public water supplies at Sheldon and Bronaugh have changed from a predominantly sodium bicarbonate-type water to a sodium chloride type. Water from Vernon County Public Water Supply District 1 at Moundville remains a sodium bicarbonate-type, but the concentration of bicarbonate is decreasing and that of chloride is increasing. Water from Nevada and Schell City remains principally a sodium chloride-type. The public supply at Rich Hill, in Bates County, remains a sodium chloride-type, with a dissolved-solids concentration that has not changed significantly, but chloride has increased since the early 1960's. Water can be classified as nonsaline to at least slightly saline in the Cambrian-Ordovician aquifer.

Calcium-to-magnesium ratios from water primarily in the Cambrian-Ordovician aquifer ranged from 1.1 to 1.4 meq/l during 1982. These ratios are consistent with those mentioned by Barks (1977) and Harvey (1980) for dolomitic rocks.

As groundwater is increasingly exploited for irrigation, sodium-salinity hazards are becoming a new problem. Extended use of excessively mineralized water on agricultural lands can lead to undesirable changes in physical and chemical characteristics of soils and affect their productivity if they lack adequate leaching (Hem, 1970).

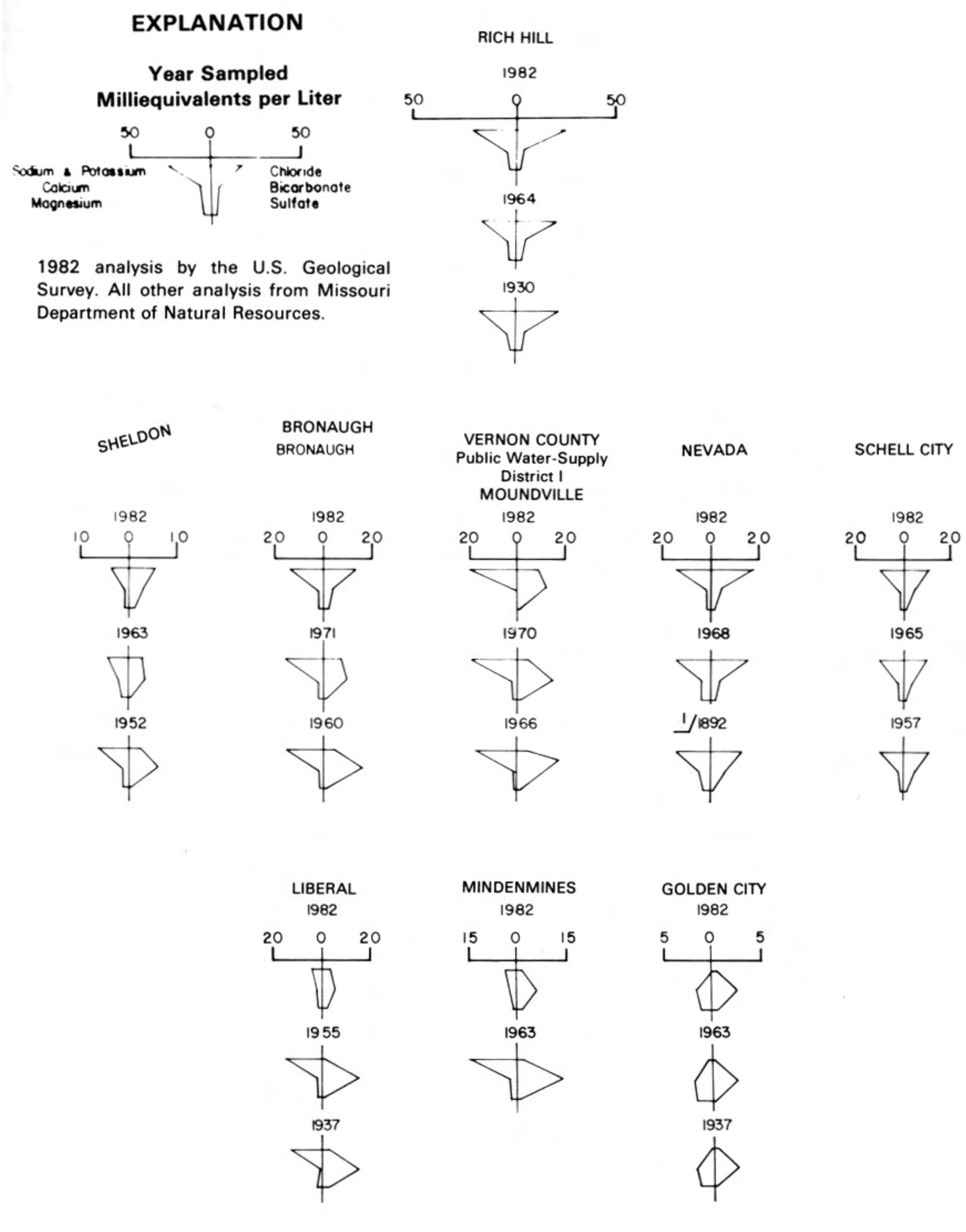
The U.S. Salinity Laboratory staff (1954) devised a method to classify irrigation water according to a sodium-adsorption ratio (SAR) versus specific-conductance plot. Analyses of water from the Cambrian-Ordovician aquifer (table 4) were plotted on a modified version of the U.S. Salinity Laboratory chart (fig. 27). Sodium-salinity classes are explained in detail in Supplemental Data in this report.

All tested water from Barton County ranged in the medium- to high-salinity-hazard category and in the low-sodium-hazard category. Tested water from Vernon County ranged from high- to very high-salinity hazard and low- to very high-sodium hazard. Tested water from Bates County was in the very high-salinity-hazard category and the very high-sodium-hazard category.

Groundwater Use

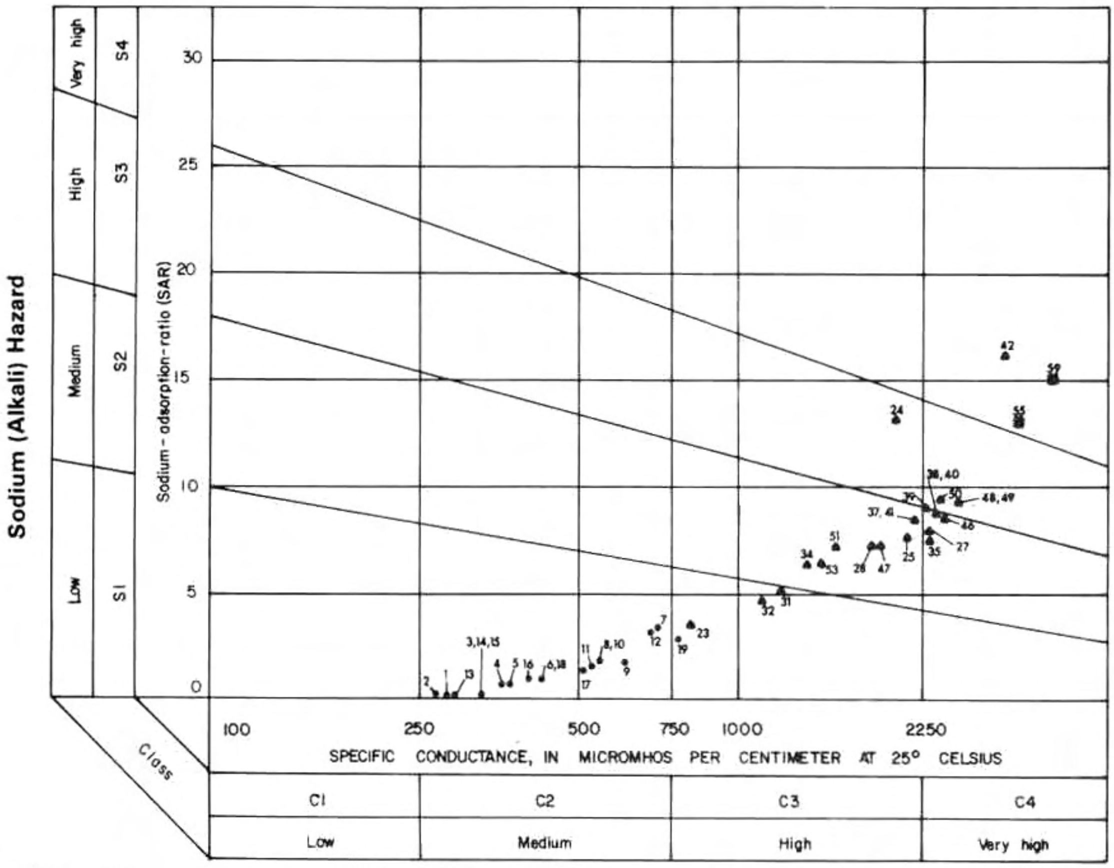
Groundwater supplies domestic, livestock, municipal, institutional, irrigation, and industrial water needs in Barton, Vernon, and Bates Counties. Current estimates show the largest use is industrial, and the second largest, public water supply.

Groundwater accounts for more than one-third of the water used for domestic



1/ Analysis by Schweitzer, 1892 (Shepard, 1907, p. 121)

Figure 26 — Stiff diagrams for water samples from public water supplies.



(Note: Chart modified from U.S. Salinity Laboratory staff, 1954)

Salinity Hazard

EXPLANATION

Barton County Water Analysis — Number indicates well number from table 4

Vernon County Water Analysis

Bates County Water Analysis

Figure 27 — Classification of sodium-salinity hazard of irrigation water in Barton, Vernon, and Bates Counties.

purposes and livestock in rural areas. In Barton and southern Vernon Counties, domestic wells generally are completed in the Mississippian aquifer. In northern Vernon and Bates Counties, wells generally are shallow, low yield, and produce only from the Pennsylvanian aquifer, but are adequate for these purposes.

It was beyond the scope of this study to measure rural water use directly. The water-use figures in this report are estimated, using census reports for the rural county areas. Population and livestock totals were obtained and per-capita use assigned each; results are summarized in table 5.

Because rural water use is directly proportional to population, projected population trends are needed to estimate future rural water use. Since 1890 the population of all three counties has steadily decreased; only during the past 20 years have population trends in the study area stabilized. With a stabilizing population and a recent increase of

TABLE 5

Summary of water use

(Values expressed in million gallons per day. All data calculated for 1980, except irrigation data, which were based on a 1981 survey; –, no data available)

Use	Barton Groundwater	Barton Surface water	Vernon Groundwater	Vernon Surface water	Bates Groundwater	Bates Surface water
Rural	0.212	0.442	0.329	0.235	0.306	0.809
Public supply	.830	.500	2.544	–	.500	1.118
Irrigation	.292	2.356	.488	1.028	–	.196
Industrial	.115	.073	3.520	7.881	1.625	1.083
TOTAL	1.449	3.371	6.881	9.144	2.431	3.206

public water-supply districts in the area, a general decrease in rural water use from private wells is expected.

Many of the incorporated cities have public water-supply systems that depend on wells open to the Cambrian-Ordovician aquifer. During the mid-1960's all three counties began forming public-water supply districts to supply residents of rural areas with dependable water sources. In 1980 there were two public water-supply districts in Barton County, both using deep wells; six public water-supply districts in Vernon County, all using deep wells; and four public water-supply districts in Bates County, all using surface water (Missouri Department of Natural Resources, 1980).

Several cities have changed to surface-water impoundments for water sources, because of degraded groundwater quality in their areas. During 1982 the city of Nevada began using reverse osmosis for water purification to help alleviate water-quality problems. In Bates County it is not uncommon for residents or institutions to receive water hauled from miles away.

The most accurate figures for public-water-supply use are given in a Missouri Department of Natural Resources publication (1980). Table 6 lists average daily consumption and shows that water use from public water supplies nearly tripled between 1962 and 1980.

Use of groundwater for center-pivot irrigation systems began in Barton County during the middle 1960's and continued to increase through the 1970's. Irrigation wells in the study area typically are drilled into the Roubidoux Formation or Gasconade Dolomite, and casing is set in the Keokuk and Burlington Limestone.

In the summer of 1981 an irrigation water-use survey was made to estimate the quantity of groundwater used for irrigation in Barton, Vernon, and Bates Counties. On selected wells, vibration timers were installed on the power plants used to operate irrigation pumps, and pumping rates were determined by a sonic flow meter. The product of actual pumping time and pumping rate is the total gallons of water pumped. As verification, owners of the individual irrigation systems reported the number of hours wells were pumped. Results of this survey are shown in table 7.

The total pumpage shown in table 7 needs to be considered a minimum, because no data were available for 33 percent of the known irrigation wells in the three counties. Irrigation water use is seasonal, and expressing it in million gallons per day can be misleading (table

TABLE 6

Water use from public water supplies, 1962-1980

(Average daily consumption, in million gallons per day. PWSD refers to Public Water-Supply District)

Public Supply	Begin year	1962	1966	1969	1971	1973	1975	1977	1980	Source
				Barton County						
Lamar	1931	0.350	0.350	0.450	0.400	0.500	0.500	0.500	0.500	Surface
Golden City	1937	.040	.100	.060	.060	.060	.060	.060	.090	Well
Mindenmines	1964	—	.008	.019	.019	.020	.025	.025	.025	Well
Barton County PWSD Well 1	1966	—	—	—	.150	.200	.300	.300	.500	Well
Barton County PWSD Well 2	1967	—	—	.015	.043	.040	.040	.040	.040	Well
Liberal	1937	.060	.080	.080	.080	.125	.130	.130	.175	Well
TOTAL		0.450	0.538	0.624	0.752	0.945	1.055	1.055	1.300	
				Vernon County						
Bronaugh	1960	0.020	0.020	0.020	0.016	0.030	0.020	0.025	0.030	Well
Nevada	1885	.700	.700	800	1.100	1.100	1.200	1.500	1.500	Well
Schell City	1958	.010	.015	.015	.015	.050	.060	.080	.150	Well
Sheldon	1952	.018	.020	.005	.050	.050	.050	.070	.085	Well
Walker	1965	—	.015	.030	.030	.030	.040	.040	.065	Well
Vernon County PWSD Well 1	1965	—	.006	.020	.035	.040	.040	.040	.060	Well
Vernon County PWSD Well 2	1966	—	—	.004	.010	.015	.015	.015	.070	Well
Vernon County PWSD Well 3	1968	—	—	.012	.012	.030	.060	.060	.133	Well
Vernon County PWSD Well 4	1966	—	—	—	.035	.060	.070	.100	.185	Well
Vernon County PWSD Well 5	1966	—	—	.005	.006	.008	.008	.008	.016	Well
Vernon County PWSD Well 7	1972	—	—	—	—	—	.040	.070	.070	Well
State Hospital	1977	—	—	—	—	—	—	.500	.180	Well
TOTAL		0.748	0.776	0.911	1.309	1.413	1.603	2.508	2.544	
				Bates County						
Adrian	1938	0.017	0.065	0.075	0.075	0.125	0.200	0.180	0.190	Surface
Amoret	1966	—	.022	.015	.007	.010	.021	.021	.030	Surface
Butler	1915	.438	.438	.400	.400	.300	.500	.710	.703	Surface
Hume	1955	.020	.025	.020	.020	.020	.020	.020	.022	Surface (Well to 1975)
Rockville	1969	—	—	—	.005	.005	.009	.017	.028	Surface
Rich Hill	1913	.200	.200	.300	.700	.700	.471	.500	.500	Well
Bates County PWSD Well 1	1965	—	—	.008	.009	.012	.011	.019	.021	Surface
Bates County PWSD Well 2	1967	—	—	—	.025	.025	.047	.060	.044	Surface
Bates County PWSD Well 3	1970	—	—	—	.012	.015	.022	.020	.020	Surface
Bates County PWSD Well 4	1975	—	—	—	—	—	—	.050	.060	Surface
TOTAL		0.675	0.750	0.818	1.253	1.212	1.301	1.597	1.618	

TABLE 7

Groundwater withdrawal for irrigation use, 1981

Location	Time pumped (hours)	Withdrawal rate (gallons per minute)	Total withdrawal (million gallons)
	Barton County		
T. 31 N., R. 31 W., sec. 17daa	213	[1]804	10.3
T. 31 N., R. 31 W., sec. 20abc	103	800	4.9
T. 31 N., R. 32 W., sec. 10dbb	310	800	14.9
T. 31 N., R. 32 W., sec. 15adc	161	[1]804	7.8
T. 31 N., R. 32 W., sec. 21ccb	21	1,000	1.3
T. 31 N., R. 32 W., sec. 22adc	342	[1]804	16.5
T. 31 N., R. 33 W., sec. 8dad	[1]188	1,200	13.5
T. 31 N., R. 33 W., sec. 20bdd	[1]188	,500	5.6
T. 31 N., R. 33 W., sec. 30daa	[1]188	525	5.9
T. 32 N., R. 31 W., sec. 18caa	250	[1]804	12.1
T. 32 N., R. 31 W., sec. 29dbd	55	800	2.6
T. 33 N., R. 30 W., sec. 28cac	235	[1]804	11.3
TOTAL			[2]106.7
	Vernon County		
T. 36 N., R. 29 W., sec. 7dbd	287	1,000	17.2
T. 36 N., R. 29 W., sec. 9baa	193	1,200	13.9
T. 36 N., R. 29 W., sec. 1aca	200	700	8.4
T. 36 N., R. 32 W., sec. 1bdb	292	700	12.3
T. 36 N., R. 32 W., sec. 3caa	400	900	21.6
T. 36 N., R. 32 W., sec. 4cca	230	[1]856	11.8
T. 36 N., R. 32 W., sec. 7dbd	200	1,000	12.0
T. 36 N., R. 32 W., sec. 30aca	142	700	6.0
T. 37 N., R. 29 W., sec. 8dcb	[1]265	876	13.9
T. 37 N., R. 31 W., sec. 36abd	428	1,000	25.7
T. 37 N., R. 32 W., sec. 15acc	300	750	13.5
T. 37 N., R. 32 W., sec. 16bad	200	750	9.0
T. 37 N., R. 32 W., sec. 32bac	302	700	12.7
TOTAL			178.0

[1]Estimated as mean value for entire county

[2]Data not available for 44 percent of known irrigation wells in Barton County; total pumpage shown is the minimum

5). The quantity of water that is actually pumped intermittently for 3 or 4 months is averaged for an entire year. The results appear to be relatively small total pumpage rates, whereas, actually, large quantities of water are withdrawn for short periods while the irrigation systems are operational.

Because of current agricultural economic conditions, irrigated acreage has stabilized in the study area, but another prolonged drought could result in substantially increased irrigation, and construction of additional irrigation wells. During 1983, due to potential sodium-salinity hazards, several irrigators in northern Vernon County capped their irrigation wells and constructed surface-water impoundments for irrigation water supplies.

Groundwater for industrial use comes from wells completed in the Cambrian-Ordovician aquifer. Until recently (1983), Missouri laws did not require water-use registration. Consequently, industrial water-use data are based on industries and occupations of persons in specific areas in each county. The water-use data were derived by the Missouri Department of Natural Resources, using a computer model based on data from the Office of Business Research and Analysis (Don Hammer, Missouri Department of Natural Resources, written commun., 1980). Reported industrial water-use figures in table 5 are considered approximations.

Estimated energy-related water use in Barton, Vernon, and Bates Counties during 1978 was approximately 0.28, 1.01, and 1.71 mgd respectively (Don Hammer, Missouri Department of Natural Resources, written commun., 1983). These county water-use figures were not separated into groundwater and surface-water sources and for this reason were not included in table 5. Energy-related uses are numerous, including oil and coal extraction, power-plant cooling, and stack scrubbing. Future demand for water for energy-related uses mostly depends on the oil market. Energy-related water use has decreased since 1980.

SUMMARY AND CONCLUSIONS

The Pennsylvanian aquifer is used for farm and domestic water supplies, but its general effect is that of a leaky confining bed for the underlying Mississippian aquifer. Yields from wells open to Pennsylvanian rocks range from less than 1 to as much as 40 gpm locally.

A mass water-level measurement in wells completed in the Pennsylvanian aquifer shows that the water table reflects topography and that the direction of groundwater movement resembles that of the surface-water drainage. There is evidence that the cyclic deposits of limestone, sandstone, and shale have caused locally confined conditions in the Pennsylvanian aquifer. Water levels fluctuate with climatic conditions; during a long time, however, discharge is balanced by recharge and water levels do not change substantially. Water quality in the Pennsylvanian aquifer varies. The water is mostly a sodium chloride-type; it may generally be classified as moderately saline.

Where overlain by Pennsylvanian strata, the Mississippian aquifer is under confined conditions; yields range from 3 to 60 gpm and average about 15 to 20 gpm. The aquifer is mostly recharged by precipitation in the outcrop area, south and east of the study area. Where the Pennsylvanian aquifer is a leaky confining layer, water from the Pennsylvanian aquifer also probably recharges the Mississippian aquifer. Comparison of historical and 1982 potentiometric maps shows that the general direction of groundwater movement has continued to be northwestward; locally, water levels have declined in the Mississippian aquifer, near large-production well fields. Review of historical water-level data from the surrounding Tri-State Mining District indicates there has been no substantial regional water-level decline in the Mississippian aquifer.

Water quality in the Mississippian aquifer varies areally, but data are insufficient to indicate local variations. Water ranges from a sodium bicarbonate-type to a sodium chloride-type and is classified as nonsaline to moderately saline.

The Cambrian-Ordovician aquifer is a confined system overlain by relatively impervious Kinderhookian rocks and, in particular, the Northview Formation. Yields of as much as 1200 gpm can be obtained from zones in the aquifer. During drilling of a well in Nevada, static water-level measurements at different depths showed that the formations constituting the Cambrian-Ordovician aquifer are hydraulically connected.

The Cambrian-Ordovician aquifer is mostly recharged by precipitation in the Salem Plateau of south-central Missouri. In the study area, overlying Mississippian and Pennsylvanian deposits buffer water-level fluctuations from local climatic conditions. Comparison of the historical Cambrian-Ordovician potentiometric map with a 1982 map shows that groundwater movement has mainly continued to be westward and northwestward. Near Nevada, water levels in this aquifer have declined as much as 80 ft since the early 1900's. Hydrograph data from a well in the city of Lamar show a continued water-level decline, which appears to have accelerated with recently increased withdrawal from the aquifer.

Water quality in the Cambrian-Ordovican aquifer varies greatly in the study area. Water changes from a calcium magnesium-bicarbonate type in the southeastern part of the area to a sodium chloride-type toward the northwest. The water is classified as nonsaline in southeast Barton County, but dissolved-solids concentration increases toward the northwest, where the water is moderately saline. The position of the freshwater-saline transition zone has not substantially moved during recent years, but minor fluctuations are occurring along the boundary zone. Water from public-supply wells in western Barton and Vernon Counties has become a sodium chloride-type with no appreciable change in dissolved-solids concentration. A sodium-salinity hazard exists for users of deep groundwater on agricultural lands and crops. Soil conditions need to be closely monitored for adverse trends.

The principal groundwater use in the three-county area is industrial, followed by pumpage for public water supplies. An accurate irrigation water-use total could not be obtained for the area; therefore, the effects of this substantial groundwater withdrawal are not fully known. Because groundwater quality varies throughout most of the area, surface-water impoundments provide many water supplies. In the near future only an increase in public water supply and possibly industrial water use is expected. Because use of water for irrigation depends on climatic conditions, it is impossible to predict future withdrawals.

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SUPPLEMENTAL DATA

TABLE 8

Summary of water-level measurements in wells completed in the Pennsylvanian aquifer

(±, plus or minus; >, greater than; +, plus; ≈, nearly equal to; ––, no data available)

Location	Altitude of land surface (ft above sea level)	Well depth (ft)	Casing depth (ft)	Altitude of water level (ft above sea level)	Date measured
		Barton County			
T. 33 N., R. 31 W., sec. 6ddd	835	64	––	820	6/82
T. 33 N., R. 31 W., sec. 9aaa	910	152	––	885	6/82
T. 33 N., R. 31 W., sec. 17caa	900	––	––	885	6/82
T. 33 N., R. 32 W., sec. 13cca	921	shallow	––	918	6/82
		Vernon County			
T. 34 N., R. 31 W., sec. 2ddd	915	80	––	907	6/82
T. 34 N., R. 31 W., sec. 5ccb	904	34	––	884	6/82
T. 34 N., R. 31 W., sec. 6cd	870	100±	––	865	6/82
T. 34 N., R. 31 W., sec. 16adb	915	95	––	875	6/82
T. 34 N., R. 31 W., sec. 16ddb	922	12	––	917	6/82
T. 34 N., R. 31 W., sec. 17bcc	870	>50	––	858	6/82
T. 34 N., R. 31 W., sec. 21cbb	905	50	––	900	6/82
T. 34 N., R. 31 W., sec. 21dbb	930	20	––	924	6/82
T. 34 N., R. 31 W., sec. 27bbc	880	10	––	Flowing	6/82
T. 34 N., R. 31 W., sec. 28add	880	80	––	870	6/82
T. 34 N., R. 31 W., sec. 29cbb	900	10	––	897	6/82
T. 34 N., R. 32 W., sec. 1aac	860	40	––	848	6/82
T. 34 N., R. 32 W., sec. 3aab	845	95	––	833	6/82
T. 34 N., R. 32 W., sec. 5bab	840	165	––	810	6/82
T. 34 N., R. 32 W., sec. 9bbb	830	20	––	825	6/82
T. 34 N., R. 32 W., sec. 12ada	835	>50	––	823	6/82
T. 34 N., R. 32 W., sec. 28bbc	900	12	––	895	6/82
T. 34 N., R. 33 W., sec. 1aab	812	16	––	808	6/82
T. 34 N., R. 33 W., sec. 1abb	807	60	––	801	6/82
T. 34 N., R. 33 W., sec. 3aad	800	25	––	796	6/82
T. 34 N., R. 33 W., sec. 4bbc	785	100	––	775	6/82
T. 34 N., R. 33 W., sec. 20bab	820	80	––	818	6/82
T. 34 N., R. 33 W., sec. 24dad	870	24	––	864	6/82
T. 34 N., R. 33 W., sec. 29dcb	800	200	––	730	6/82
T. 34 N., R. 33 W., sec. 35dda	865	35	––	860	6/82
T. 35 N., R. 31 W., sec. 29dcd	780	34	––	759	6/82
T. 35 N., R. 31 W., sec. 29dcd	780	90	––	742	6/82
T. 35 N., R. 31 W., sec. 32aba	810	30	––	806	6/82
T. 35 N., R. 31 W., sec. 33cdd	820	32	––	814	6/82
T. 35 N., R. 31 W., sec. 33dcc	830	129	––	818	6/82
T. 35 N., R. 32 W., sec. 7cca	776	103	––	758	6/82
T. 35 N., R. 32 W., sec. 15bbb	835	>50	––	825	6/82
T. 35 N., R. 32 W., sec. 16aab	852	110	––	846	6/82
T. 35 N., R. 32 W., sec. 20dda	790	120	––	750	6/82
T. 35 N., R. 32 W., sec. 21aad	822	95+	––	808	6/82
T. 35 N., R. 32 W., sec. 27cbb	820	60	––	812	6/82
T. 35 N., R. 32 W., sec. 29aad	805	140	––	765	6/82
T. 35 N., R. 32 W., sec. 30ada	810	127	––	802	6/82
T. 35 N., R. 33 W., sec. 9ddc	802	99	––	789	6/82
T. 35 N., R. 33 W., sec. 13ccc	775	20	––	761	6/82

TABLE 8 (cont.)

Location	Altitude of land surface (ft above sea level)	Well depth (ft)	Casing depth (ft)	Altitude of water level (ft above sea level)	Date measured
		Vernon County (cont.)			
T. 35 N., R. 33 W., sec. 15dda	782	100+	––	772	6/82
T. 35 N., R. 33 W., sec. 19ddd	840	20	––	836	6/82
T. 35 N., R. 33 W., sec. 26bab	791	25	––	781	6/82
T. 35 N., R. 33 W., sec. 34ada	790	18	––	784	6/82
T. 36 N., R. 31 W., sec. 9bcd	782	131	27	691	6/82
T. 36 N., R. 32 W., sec. 20ddc	785	42	––	775	6/82
T. 36 N., R. 32 W., sec. 21bba	805	195	––	785	6/82
T. 36 N., R. 32 W., sec. 21ccd	795	35	––	765	6/82
T. 36 N., R. 32 W., sec. 22ccc	785	30	20	778	6/82
T. 36 N., R. 32 W., sec. 26bbb	762	25	––	742	6/82
T. 36 N., R. 32 W., sec. 26aba	762	35	––	742	6/82
T. 36 N., R. 32 W., sec. 28bbb	791	>100	––	716	6/82
T. 36 N., R. 32 W., sec. 30dcd	780	16	––	772	6/82
T. 36 N., R. 33 W., sec. 5ccd	951	––	––	936	6/82
T. 36 N., R. 33 W., sec. 5cdc	950	21	––	947	6/82
T. 36 N., R. 33 W., sec. 13cdc	805	70	––	796	6/82
T. 36 N., R. 33 W., sec. 17bab	853	21	––	841	4/82
T. 36 N., R. 33 W., sec. 28aab	785	18	––	777	6/82
T. 36 N., R. 33 W., sec. 36ada	780	16	––	772	6/82
T. 37 N., R. 32 W., sec. 33dcd	795	25	––	787	6/82
T. 37 N., R. 33 W., sec. 1ac	912	50	––	904	6/82
T. 37 N., R. 33 W., sec. 18cdc	778	15	––	774	6/82
T. 37 N., R. 33 W., sec. 29abb	803	28	––	798	6/82
T. 38 N., R. 32 W., sec. 30cba	800	≈200	––	789	6/82
T. 38 N., R. 33 W., sec. 22dcc	860	120	––	846	6/82
		Bates County			
T. 38 N., R. 29 W., sec. 14dba	769	175	48	732	9/57
T. 38 N., R. 29 W., sec. 14adc	769	85	24	756	1/58
T. 38 N., R. 32 W., sec. 5cbb	887	95	––	873	6/82
T. 38 N., R. 32 W., sec. 10aad	910	30	––	903	6/82
T. 38 N., R. 32 W., sec. 10bbb	894	165	165	859	2/56
T. 38 N., R. 32 W., sec. 19daa	874	377	193	789	8/44
T. 38 N., R. 32 W., sec. 20bbb	888	202	66	848	6/48
T. 38 N., R. 33 W., sec. 14aaa	880	160	––	865	6/82
T. 38 N., R. 33 W., sec. 15ccc	882	shallow	––	877	6/82
T. 38 N., R. 33 W., sec. 22dcc	860	120	––	846	6/82
T. 38 N., R. 33 W., sec. 23ad	850	18	––	850	6/82
T. 39 N., R. 29 W., sec. 10daa	801	110	62	767	10/57
T. 39 N., R. 29 W., sec. 27dda	759	110	22	741	8/61
T. 39 N., R. 29 W., sec. 36bcb	800	268	160	710	2/41
T. 39 N., R. 30 W., sec. 11dab	982	395	121	732	1/54
T. 39 N., R. 31 W., sec. 20dcd	755	60	46	744	6/59
T. 39 N., R. 32 W., sec. 3bab	821	190	163	794	9/56
T. 39 N., R. 32 W., sec. 3cdb	778	160	58	763	6/55
T. 39 N., R. 32 W., sec. 4bcd	774	200	102	754	8/56
T. 39 N., R. 32 W., sec. 4ccd	772	125	87	747	11/54
T. 39 N., R. 32 W., sec. 35dab	822	30	––	816	6/82
T. 39 N., R. 33 W., sec. 2c––	818	200	57	778	8/57

TABLE 8 (cont.)

Location	Altitude of land surface (ft above sea level)	Well depth (ft)	Casing depth (ft)	Altitude of water level (ft above sea level)	Date measured
		Bates County (cont.)			
T. 39 N., R. 33 W., sec. 2cbc	793	155	123	773	1/55
T. 39 N., R. 33 W., sec. 9cdd	812	175	175	803	1/55
T. 40 N., R. 29 W., sec. 12abb	809	276	201	705	11/34
T. 40 N., R. 29 W., sec. 20bca	905	355	18	635	4/59
T. 40 N., R. 29 W., sec. 25ada	977	445	201	752	8/63
T. 40 N., R. 30 W., sec. 1ddc	905	205	17	873	9/60
T. 40 N., R. 30 W., sec. 18dcc	857	120	64	802	1/52
T. 40 N., R. 30 W., sec. 28ada	879	65	10	822	5/51
T. 40 N., R. 30 W., sec. 32cdd	908	527	39	713	2/46
T. 40 N., R. 31 W., sec. 20bcc	863	100	47	849	4/50
T. 40 N., R. 30 W., sec. 20cba	847	115	77	827	10/56
T. 40 N., R. 31 W., sec. 21acc	852	120	24	839	5/50
T. 40 N., R. 31 W., sec. 26abb	799	100	19	769	5/58
T. 40 N., R. 31 W., sec. 27cc	803	155	64	793	6/46
T. 40 N., R. 32 W., sec. 17bb	890	200	175	830	7/46
T. 40 N., R. 32 W., sec. 24cb	817	170	105	787	11/47
T. 40 N., R. 32 W., sec. 24cb	818	445	125	693	4/49
T. 40 N., R. 32 W., sec. 26aba	851	336	182	781	8/47
T. 40 N., R. 32 W., sec. 23cdc	814	135	67	762	7/53
T. 40 N., R. 33 W., sec. 28ccd	846	353	205	736	12/49
T. 41 N., R. 29 W., sec. 8bdb	928	350	40	713	9/45
T. 41 N., R. 29 W., sec. 8dad	901	285	221	701	8/55
T. 41 N., R. 29 W., sec. 8dad	905	281	237	797	9/39
T. 41 N., R. 29 W., sec. 8dd	941	344	20	721	5/45
T. 41 N., R. 29 W., sec. 9bc	944	358	60	721	7/45
T. 41 N., R. 29 W., sec. 10bab	943	360	38	713	11/45
T. 41 N., R. 29 W., sec. 18dda	908	220	53	868	6/50
T. 41 N., R. 29 W., sec. 24cbc	839	130	22	821	1/61
T. 41 N., R. 29 W., sec. 29dcc	911	363	26	701	7/50
T. 41 N., R. 30 W., sec. 11ac	834	300	30	794	8/45
T. 41 N., R. 30 W., sec. 11bd	871	370	61	716	11/45
T. 41 N., R. 30 W., sec. 29ccb	888	225	61	848	12/48
T. 41 N., R. 30 W., sec. 30cbc	903	280	40	840	6/46
T. 41 N., R. 31 W., sec. 11dcb	913	265	250	838	6/46
T. 41 N., R. 32 W., sec. 21dbd	836	100	25	766	8/58
T. 41 N., R. 32 W., sec. 25cb	880	254	39	845	9/53
T. 41 N., R. 32 W., sec. 32aba	811	125	78	791	2/65
T. 42 N., R. 29 W., sec. 16cdc	840	300	265	720	3/65
T. 42 N., R. 30 W., sec. 14dac	846	344	124	739	7/46
T. 42 N., R. 30 W., sec. 36dbd	922	105	100	910	4/66
T. 42 N., R. 31 W., sec. 15cba	825	167	150±	803	8/71
T. 42 N., R. 32 W., sec. 32cd	896	102	54	856	8/34
T. 42 N., R. 33 W., sec. 35ada	921	222	––	821	1/06

TABLE 9

Summary of water-level measurements in wells completed in the Mississippian aquifer
(+, plus; ––, no data available)

Location	Altitude of land surface (ft above sea level)	Well depth (ft)	Casing depth (ft)	Altitude of water level (ft above sea level)	Date measured
		Barton County			
T. 30 N., R. 31 W., sec. 4baa	960	335	130	880	3/25/56
T. 31 N., R. 29 W., sec. 11dcc	1,048	375	60	1,018	9/12/36
T. 31 N., R. 30 W., sec. 27ccd	961	267	18	937	9/20/46
T. 31 N., R. 30 W., sec. 27ccd	961	267	18	926	6/9/82
T. 31 N., R. 31 W., sec. 13bbb	963	361	105	888	9/1/54
T. 31 N., R. 31 W., sec. 13bbb	963	361	105	879	6/9/82
T. 31 N., R. 31 W., sec. 33cdd	958	160	115	943	1/1/56
T. 31 N., R. 32 W., sec. 10dbc	992	247	157	937	6/8/82
T. 31 N., R. 32 W., sec. 17acc	1,007	85	46	990	1/1/42
T. 32 N., R. 29 W., sec. 35ccc	1,040	420	136	982	8/9/82
T. 32 N., R. 30 W., sec. 28acd	970	402	150	787	1/5/55
T. 32 N., R. 31 W., sec. 24cca	988	330	145	818	2/9/46
T. 32 N., R. 31 W., sec. 24cbb	973	305	126	798	5/1/46
		Vernon County			
T. 34 N., R. 29 W., sec. 6aaa	920	635	130	741	6/9/82
T. 34 N., R. 30 W., sec. 25bcd	960	345	200	780	10/20/82
T. 34 N., R. 31 W., sec. 11ada	911	380	218	731	12/1/61
T. 34 N., R. 31 W., sec. 11ada	911	380	218	728	6/9/82
T. 34 N., R. 32 W., sec. 10adb	833	370	145	731	3/18/57
T. 34 N., R. 32 W., sec. 17ccd	895	450	245	715	3/1/55
T. 34 N., R. 32 W., sec. 17ccd	895	450	245	715	6/17/81
T. 34 N., R. 33 W., sec. 2bbb	795	407	210	769	10/21/82
T. 35 N., R. 30 W., sec. 32bab	872	421	189	756	5/14/81
T. 35 N., R. 31 W., sec. 20bdc	824	350	112	717	10/20/82
T. 35 N., R. 32 W., sec. 3ddd	804	380	173	717	6/11/82
T. 35 N., R. 32 W., sec. 17acb	810	391	180	719	6/17/82
T. 36 N., R. 29 W., sec. 17cdd	838	390	162	748	5/15/54
T. 36 N., R. 29 W., sec. 17cdd	838	390	162	714	6/10/82
T. 36 N., R. 31 W., sec. 2cda	783	400	180	735	6/10/82
T. 36 N., R. 31 W., sec. 36cba	878	475	240	758	5/12/49
T. 36 N., R. 31 W., sec. 36cba	878	475	240	716	6/17/82
T. 37 N., R. 32 W., sec. 33dda	795	510	490	720	9/20/48
T. 38 N., R. 32 W., sec. 29aad	938	813	570	700	1934
T. 38 N., R. 33 W., sec. 36dcb	856	645	––	699	5/21/81
T. 37 N., R. 30 W., sec. 31ccc (4 mi north of Walker)	775	400	––	[a]775+	pre-1907
T. 37 N., R. 33 W., sec. 28aa	770	345	––	[a]770+	1901
		Bates County			
T. 38 N., R. 30 W., sec. 12dcb	793	435	244	713	8/17/54
T. 38 N., R. 30 W., sec. 12dcd	787	393	273	727	3/29/43
T. 38 N., R. 31 W., sec. 14bdc	763	300	197	713	5/10/41
T. 38 N., R. 31 W., sec. 16cba	797	390	299	727	1/18/46
T. 38 N., R. 31 W., sec. 21add	797	390	298	718	6/9/82
T. 39 N., R. 30 W., sec. 25bab	869	510	376	709	10/7/54

[a]Reported as flowing well (Shepard, 1907).

TABLE 9 (cont.)

Location	Altitude of land surface (ft above sea level)	Well depth (ft)	Casing depth (ft)	Altitude of water level (ft above sea level)	Date measured
		Bates County (cont.)			
T. 39 N., R. 30 W., sec. 24ddc	809	430	300	710	3/17/44
T. 39 N., R. 32 W., sec. 31aba	850	640	280	702	10/19/82
T. 39 N., R. 33 W., sec. 15bcc	840	725	495	727	5/6/55
T. 40 N., R. 32 W., sec. 24cb	818	445	––	693	4/28/49
T. 41 N., R. 30 W., sec. 9acd	863	695	650	703	1/11/64
T. 41 N., R. 30 W., sec. 28cdb	885	604	578	695	4/30/46
T. 41 N., R. 32 W., sec. 15ccd	870	700	520	700	8/22/61
T. 38 N., R. 30 W., sec. 3dad	789	350	285	770	10/19/82
		Cedar County			
T. 33 N., R. 27 W., sec. 11ddd	982	176	20	923	6/23/67
T. 33 N., R. 28 W., sec. 9cbd	1,047	356	105	947	8/22/50
T. 33 N., R. 28 W., sec. 22ddd	961	270	52	886	1/7/37
T. 34 N., R. 29 W., sec. 1bcb	940	420	159	728	2/–/68
T. 35 N., R. 26 W., sec. 7bcc	925	258	151	765	6/7/82
T. 35 N., R. 28 W., sec. 8bab	954	425	163	729	3/25/61
T. 35 N., R. 28 W., sec. 26cdd	933	380	130	759	7/27/67
T. 35 N., R. 28 W., sec. 36acc	922	339	84	766	6/14/82
T. 36 N., R. 28 W., sec. 35ccc	940	330	43	764	10/4/50
" " "	"	"	"	744	6/11/82
		Dade County			
T. 30 N., R. 25 W., sec. 8aad	1,120	200	175	1,095	1939
T. 30 N., R. 27 W., sec. 18daa	1,150	200	175	1,100	1956
T. 31 N., R. 27 W., sec. 14bac	1,078	283	23	983	9/–/56
T. 31 N., R. 28 W., sec. 17add	1,074	525	140	1,004	3/1/57
		Henry County			
T. 43 N., R. 26 W., sec. 2dcb	940	385	369	670	2/20/64
T. 43 N., R. 27 W., sec. 26dba	790	630	415	689	7/15/81
T. 44 N., R. 24 W., sec. 36bdb	877	265	104	697	11/20/63
		St. Clair County			
T. 37 N., R. 25 W., sec. 10add	888	235	35	868	7/13/55
T. 37 N., R. 25 W., sec. 13bcb	912	210	100	835	2/23/67

[a]Reported as flowing well (Shepard, 1907).

TABLE 10

Summary of pre-1981 water-level measurements in wells completed in the Cambrian-Ordovician aquifer

(——, no data available; ≈, nearly equal to)

Location	Altitude of land surface (ft above sea level)	Well depth (ft)	Casing depth (ft)	Altitude of water level (ft above sea level)	Date measured
		Barton County			
T. 31 N., R. 29 W., sec. 23bbc	1,044	487	36	[a]847	12/17/36
T. 31 N., R. 29 W., sec. 26cdd	1,060	893	400	[a]905	2/10/37
T. 31 N., R. 29 W., sec. 26cdd	1,060	893	400	900	7/1/50
T. 32 N., R. 30 W., sec. 29ccd	970	1,861	——	[a]810	1/1/11
T. 32 N., R. 30 W., sec. 31bab	955	971	553	735	10/19/53
T. 32 N., R. 33 W., sec. 2ac	892	817	295	732	10/17/36
		Vernon County			
T. 35 N., R. 31 W., sec. 13abc	891	1,050	602	751	7/1/42
T. 37 N., R. 29 W., sec. 1add	738	440	200	724	10/28/41
T. 37 N., R. 32 W., sec. 31ada	810	2,018	——	712	≈1921
T. 38 N., R. 29 W., sec. 33ddb	780	300	115	733	6/1/52
		Flowing wells reported by Greene and Pond (1926)			
Harry Moore T. 35 N., R. 31 W., sec. 8dca	785	800	——	[a]785 + [b]12	1887
George Calvin T. 36 N., R. 29 W., sec. 26bc	760	660	——	[a]760+	pre-1926
Pence Gun Club T. 36 N., R. 31 W., sec. 8center	740	691	——	[a]740+	1922
Stutz Gun Club T. 36 N., R. 32 W., sec. 27E ctr.	745	873	——	[a]745+	1918
Ridgeway Well T. 36 N., R. 32 W., sec. 32bd	770	Roubidoux	——	[a]770 + [b]6	1920
E.S. Weyland T. 36 N., R. 33 W., sec. 30cc	765	650	——	[a]765 + [b]15	1889
		Bates County			
T. 38 N., R. 31 W., sec. 8aca	805	800	200	[a]750	12/17/27
T. 39 N., R. 32 W., sec. 24dcd	765	843	645	755	8/13/33
T. 39 N., R. 33 W., sec. 18aac	807	1,618	506	700	10/1/34
		Cedar County			
T. 33 N., R. 25 W., sec. 22bac	912	200	27	860	9/19/56
T. 34 N., R. 26 W., sec. 8dca	968	850	237	768	6/36
T. 34 N., R. 26 W., sec. 23abc	892	165	43	787	10/11/48
T. 35 N., R. 25 W., sec. 14aac	995	154	12	975	5/27/42
T. 35 N., R. 25 W., sec. 28abc	1,006	672	152	856	10/13/54
T. 35 N., R. 27 W., sec. 23dac	883	252	7	787	11/23/43
T. 36 N., R. 28 W., sec. 21bdb	842	1,046	512	[a]736	2/17
T. 36 N., R. 28 W., sec. 28bcc	916	946	550	[a]750	10/47
		Dade County			
T. 31 N., R. 26 W., sec. 19bb	1,075	1,006	361	840	1924
T. 31 N., R. 27 W., sec. 6bcd	1,033	530	36	811	8/27/36
T. 31 N., R. 27 W., sec. 31ccc	1,082	1,198	334	892	9/28
T. 32 N., R. 26 W., sec. 22dbb	992	375	62	867	7/6/46

[a]Water levels used on historic Cambrian-Ordovician potentiometric map.

[b]Level to which water rose in extended riser pipe.

TABLE 10 (cont.)

Location	Altitude of land surface (ft above sea level)	Well depth (ft)	Casing depth (ft)	Altitude of water level (ft above sea level)	Date measured
		Dade County (cont.)			
T. 32 N., R. 26 W., sec. 36da	1,008	300	16	923	2/2/36
T. 33 N., R. 25 W., sec. 29dac	910	100	30	869	9/3/53
		Henry County			
T. 40 N., R. 26 W., sec. 14abd	734	826	350	Flowing	5/30/15
T. 41 N., R. 26 W., sec. 2baa	800	587	294	715	6/2/39
T. 41 N., R. 26 W., sec. 3daa	808	930	378	728	1/3/16
T. 41 N., R. 28 W., sec. 27dcb	783	1,045	404	720	7/52
T. 43 N., R. 24 W., sec. 1a——	863	560	260	722	1/31
T. 43 N., R. 24 W., sec. 9——	834	1,011	482	724	11/20/33
T. 43 N., R. 24 W., sec. 15bac	849	1,020	487	739	4/1/42
		St. Clair County			
T. 36 N., R. 25 W., sec. 1caa	908	222	43	818	8/7/40
T. 38 N., R. 25 W., sec. 17aac	725	550	138	715	5/25/46
T. 38 N., R. 25 W., sec. 30aa	791	339	251	721	10/18/47
T. 39 N., R. 24 W., sec. 1acc	753	221	113	723	7/14/48
T. 39 N., R. 24 W., sec. 33cca	890	650	250	740	4/1936
T. 39 N., R. 28 W., sec. 5daa	769	1,190	300	[a]720	1891
		Kansas			
		Wells reported by Frick (1980)			
T. 25 N., R. 24 E., sec. 36	915	1,400	750	715	1953
T. 29 N., R. 23 E., sec. 24	991	1,187	790	770	3/29
T. 29 N., R. 25 E., sec. 5	1,020	1,172	490	722	3/13/46
T. 30 N., R. 25 E., sec. 9	952	1,064	350	732	6/39
		Well reported by Stramel (1957)			
T. 30 S., R. 25 E., sec. 19daa	941	Ordovician	250	[a]831	1882

[a]Water levels used on historic Cambrian-Ordovician potentiometric map.

[b]Level to which water rose in extended riser pipe.

TABLE 11

Summary of water-level measurements in wells completed in the Cambrian-Ordovician aquifer

(——, no data available)

Location	Altitude of land surface (ft above sea level)	Well depth (ft)	Casing depth (ft)	Spring 1981	Summer 1981	Fall 1981	Summer 1982	Fall 1982
Barton County								
T. 31 N., R. 29 E., sec. 20aab	1,129	900	525	747.7	——	——	746.0	[a]751.3
T. 31 N., R. 30 E., sec. 11ddb	980	930	——	738.3	——	736.7	[a]743.5	[a]738.0
T. 31 N., R. 30 E., sec. 20dab	942	1,100	450	——	721.2	732.3	[a]728.8	——
T. 31 N., R. 29 E., sec. 35bbb	1,063	1,100	400	[b]851.4	——	——	[b,a]862.4	[a]864
T. 31 N., R. 31 E., sec. 4bac	970	1,050	——	699.4	——	683.7	——	[a]695.6
T. 31 N., R. 31 E., sec. 4cac	970	1,100	——	699.0	693.0	[c]664.5	[a]702.7	694.5
T. 31 N., R. 31 E., sec. 5aca	984	1,050	——	697.1	691.6	——	[a]701.2	[a]689.1
T. 31 N., R. 31 E., sec. 17daa	970	1,050	——	696.8	690.5	[c]615.0	[a]701.6	[a]692.3
T. 31 N., R. 31 E., sec. 20abc	1,002	1,176	400	693.1	——	[c]656.5	[a]701.2	[a]690.0
T. 31 N., R. 32 E., sec. 6cbc	964	1,050	——	688.9	——	686.2	[a]696.6	[a]686.5
T. 31 N., R. 32 E., sec. 6dac	970	1,050	——	690.0	——	689.2	[a]701.7	——
T. 31 N., R. 32 E., sec. 10dbb	990	1,116	450	694.2	——	——	[a]700.7	[a]691.6
T. 31 N., R. 32 E., sec. 21ccb	950	1,100	500	——	——	700.0	——	——
T. 31 N., R. 32 E., sec. 22aaa	999	900	552	698.6	——	[c]674.0	[b,a]703.3	[a]696.5
T. 31 N., R. 32 E., sec. 22adc	970	1,150	——	709.6	——	——	——	[a]701.6
T. 31 N., R. 32 E., sec. 22adc	970	1,150	——	704.6	——	——	——	——
T. 31 N., R. 32 E., sec. 30dcb	910	1,125	——	748.0	——	754.8	766.8	747.6
T. 31 N., R. 33 E., sec. 5bbc	976	910	640	690.1	——	690.1	[b,a]696.2	[a]690.0
T. 31 N., R. 33 E., sec. 5bbc	976	910	640	——	——	[c]669.1	——	——
T. 31 N., R. 33 E., sec. 20bdd	950	1,090	234	755.0	——	687.0	[a]696.0	[a]688.0
T. 31 N., R. 33 E., sec. 20bdd	950	1,090	234	753.0	——	——	——	——
T. 31 N., R. 33 E., sec. 30daa	955	1,100	239	695.4	——	690.4	[a]702.0	[a]692.1
T. 31 N., R. 33 E., sec. 30daa	955	1,100	239	694.0	——	——	——	——
T. 32 N., R. 30 E., sec. 27add	1,040	940	542	717.4	——	——	[b,a]719.4	[b,a]713.9
T. 32 N., R. 30 E., sec. 31bab	1,955	971	553	——	[c]694.4	——	[b,a]710.9	[a]693.6
T. 32 N., R. 30 E., sec. 32acc	960	1,150	375	——	——	[c]640.0	691.8	[a]701.6
T. 32 N., R. 30 E., sec. 32acc	960	1,150	375	——	——	694.0	——	——
T. 32 N., R. 31 E., sec. 17aaa	992	900	552	693.5	——	——	[b,a]694.2	[a]691.9
T. 32 N., R. 31 E., sec. 18caa	992	1,180	478	694.3	——	672.0	[a]699.2	[a]701.6
T. 32 N., R. 31 E., sec. 29dbd	993	1,040	350	700.7	——	688.4	[a]707.4	[a]693.5
T. 32 N., R. 31 E., sec. 29dbd	993	1,040	350	694.8	——	——	——	——
T. 32 N., R. 32 E., sec. 33ccc	991	1,440	191	687.2	——	737.5	[b,a]692.0	[a]684.0
T. 32 N., R. 32 E., sec. 33ccc	991	1,440	191	685.0	——	——	——	——
T. 32 N., R. 33 E., sec. 2acd	902	828	505	[b]691.6	——	[c]679.6	[a]695.6	[a]692.6
T. 33 N., R. 30 E., sec. 28ac	992	1,108	485	713.5	——	——	——	——
Vernon County								
T. 34 N., R. 31 E., sec. 35aad	922	930	207	717.0	——	——	——	[a]717.2
T. 34 N., R. 31 E., sec. 35adc	920	930	300	715.0	——	713.9	[a]717.6	——
T. 34 N., R. 32 E., sec. 5aaa	865	785	309	665.5	——	——	[a]703.0	[a]697.7
T. 34 N., R. 32 E., sec. 20baa	910	853	280	701.0	——	700.7	[a]703.9	[a]700.7
T. 35 N., R. 31 E., sec. 5bad	842	1,095	275	715.7	——	725.0	[a]719.4	[c,a]697.4

[a]Water level used on 1982 Cambrian-Ordovician potentiometric map.

[b]Water recently pumped.

[c]Pumping measurement.

TABLE 11 (cont.)

Location	Altitude of land surface (ft above sea level)	Well depth (ft)	Casing depth (ft)	Spring 1981	Summer 1981	Fall 1981	Summer 1982	Fall 1982
			Vernon County (cont.)					
T. 35 N., R. 31 E., sec. 5dba	851	1,100	272	[c]648.4	696.0	685.4	[c,a]683.4	[c,a]695.4
T. 35 N., R. 31 E., sec. 13abc	891	1,050	602	722.4	—	724.9	[a]725.0	[a]722.5
T. 36 N., R. 29 E., sec. 7dbd	839	832	214	718.8	—	—	[a]723.1	[a]720.2
T. 36 N., R. 29 E., sec. 9baa	860	1,008	400	698.8	—	698.5	703.2	700.6
T. 36 N., R. 31 E., sec. 29dca	848	1,020	544	—	—	728.0	[a]710.2	[a]707.3
T. 36 N., R. 32 E., sec. 1aca	800	900	250	705.1	—	706.0	[a]713.0	[a]709.4
T. 36 N., R. 32 E., sec. 1bdb	813	900	250	705.3	—	706.2	[a]713.5	[a]709.4
T. 36 N., R. 32 E., sec. 3caa	803	900	300	704.6	—	—	[a]712.6	[a]708.7
T. 36 N., R. 32 E., sec. 6adb	797	700	70	—	—	—	[a]708.3	[a]710.2
T. 36 N., R. 32 E., sec. 7dbd	800	900	300	700.1	—	700.7	[a]709.4	[a]705.4
T. 36 N., R. 32 E., sec. 22dbc	773	900	300	—	—	665.6	[a]712.4	[a]709.8
T. 36 N., R. 32 E., sec. 30aca	790	880	250	707.5	—	—	[a]714.4	[a]710.8
T. 36 N., R. 33 E., sec. 8ddb	844	1,820	—	—	—	—	[a]712.1	[a]708.3
T. 37 N., R. 29 E., sec. 8dcb	845	1,110	503	—	—	—	—	[a]716.9
T. 37 N., R. 30 E., sec. 10cdc	765	1,130	320	710.9	—	712.3	[a]715.2	[a]714.3
T. 37 N., R. 31 E., sec. 36abd	775	883	250	705.4	—	707.3	[a]712.1	[a]709.4
T. 37 N., R. 32 E., sec. 15aac	775	890	—	—	—	—	[a]713.4	[a]709.6
T. 37 N., R. 32 E., sec. 16bad	770	892	500	—	705.3	—	[a]712.8	[a]708.7
T. 37 N., R. 32 E., sec. 29ddb	772	1,205	—	—	713.8	—	[a]724.9	[a]720.4
T. 37 N., R. 32 E., sec. 31ada	810	2,018	—	—	712.0	—	[a]719.8	[a]715.5
T. 38 N., R. 29 E., sec. 33ddd	755	714	317	—	—	707.4	[a]711.0	[a]719.9
			Bates County					
T. 38 N., R. 29 E., sec. 2cbc	750	1,760	120	—	702.2	703.4	[a]710.4	[a]710.4
T. 38 N., R. 29 E., sec. 10cbb	727	1,760	120	—	703.0	705.5	[a]709.5	—
T. 38 N., R. 29 E., sec. 14dba	762	1,780	120	—	712.0	714.3	716.6	715.8
T. 38 N., R. 29 E., sec. 18ccd	744	510	260	—	707.4	—	[a]711.6	[a]709.1
T. 38 N., R. 31 E., sec. 20cdb	810	520	484	—	769.9	—	769.8	766.0
T. 39 N., R. 29 E., sec. 29ccd	781	990	350	—	703.5	704.7	[a]702.7	[a]700.4
T. 39 N., R. 32 E., sec. 24dcd	765	843	645	—	712.8	—	[a]713.4	[a]712.2
			Cedar County					
T. 33 N., R. 25 E., sec. 14bbb	930	220	20	—	—	874.8	878.3	—
T. 33 N., R. 28 E., sec. 9aad	1,027	925	505	—	740.0	—	—	40.0
T. 33 N., R. 28 E., sec. 16bbb	1,020	1,215	—	—	—	—	679.0	—
T. 33 N., R. 28 E., sec. 22daa	961	650	120	—	796.8	—	815.2	815.0
T. 34 N., R. 26 E., sec. 17aad	990	1,044	325	—	744.0	—	744.0	746.0
T. 34 N., R. 26 E., sec. 29cdb	1,064	525	305	—	742.9	—	733.5	[c]725.6
T. 36 N., R. 26 E., sec. 31cca	825	275	96	—	737.0	—	739.9	738.8
T. 36 N., R. 27 E., sec. 15bca	920	262	25	—	732.5	—	729.3	733.0
T. 36 N., R. 28 E., sec. 28ddb	954	1,050	570	—	716.7	—	715.5	[b]715.2

[a]Water level used on 1982 Cambrian-Ordovician potentiometric map.

[b]Water recently pumped.

[c]Pumping measurement.

TABLE 11 (cont.)

Location	Altitude of land surface (ft above sea level)	Well depth (ft)	Casing depth (ft)	Spring 1981	Summer 1981	Fall 1981	Summer 1982	Fall 1982
			Dade County					
T. 30 N., R. 28 E., sec. 4cdb	1,100	1,100	300	––	––	––	962.0	––
T. 30 N., R. 28 E., sec. 21acc	1,115	1,115	250	––	––	––	1,001.5	––
T. 30 N., R. 28 E., sec. 26bac	1,160	1,190	80	––	––	978.9	––	984.4
T. 31 N., R. 27 E., sec. 31ccc	1,082	1,197	334	––	––	––	––	866.3
T. 31 N., R. 28 E., sec. 36bcb	1,082	1,300	625	––	––	––	––	723.9
T. 30 N., R. 28 E., sec. 16cdb	––	––	––	––	––	––	1,003.0	––
			Henry County					
T. 40 N., R. 26 E., sec. 14––	750	604	255	––	––	694.5	694.1	693.7
T. 40 N., R. 26 E., sec. 20ccb	782	430	55	––	––	694.5	697.7	696.1
T. 40 N., R. 27 E., sec. 15cdc	813	490	278	––	––	665.0	709.7	709.4
T. 41 N., R. 24 E., sec. 20cca	841	490	300	––	––	677.4	708.7	––
T. 41 N., R. 24 E., sec. 30abc	842	364	364	––	––	697.5	697.9	––
T. 41 N., R. 25 E., sec. 15bba	812	390	290	––	––	698.7	700.4	––
T. 41 N., R. 26 E., sec. 33aba	803	745	348	––	––	695.1	696.5	695.5
T. 41 N., R. 27 E., sec. 22ada	767	222	186	––	––	688.9	692.0	––
T. 41 N., R. 28 E., sec. 7cdc	941	635	474	––	––	700.0	686.7	685.8
T. 41 N., R. 28 E., sec. 11cbb	871	320	230	––	––	692.8	693.5	––
T. 42 N., R. 24 E., sec. 22abc	782	460	295	––	––	745.7	715.6	––
T. 42 N., R. 25 E., sec. 28bcc	817	275	167	––	––	––	685.9	––
T. 42 N., R. 26 E., sec. 36acb	796	540	412	––	690.8	––	691.6	690.8
T. 43 N., R. 24 E., sec. 2abb	860	1,350	420	––	––	––	705.0	––
T. 43 N., R. 24 E., sec. 31bcd	821	745	377	––	––	––	626.0	––
T. 43 N., R. 28 E., sec. 34dcb	790	476	240	––	679.3	––	671.3	––
T. 44 N., R. 24 E., sec. 36bdc	880	265	265	––	692.6	––	686.6	––
T. 44 N., R. 26 E., sec. 32bba	893	690	390	––	771.5	––	[b]692.0	––
T. 40 N., R. 28 E., sec. 22cac	––	––	––	––	––	700.0	697.0	––
			Jasper County					
T. 29 N., R. 29 E., sec. 6bcc	1,050	900	450	––	938.7	[c]890.0	963.4	949.4
T. 29 N., R. 30 E., sec. 1acc	1,032	472	18	––	928.8June	––	950.4	––
T. 29 N., R. 30 E., sec. 1acc	1,032	472	18	––	923.5July	––	––	––
T. 29 N., R. 30 E., sec. 1acd	1,070	1,300	––	––	926.7	914.7	––	939.1
T. 29 N., R. 30 E., sec. 3aaa	1,030	1,010	442	––	903.1	[c]826.7	915.6	911.5
T. 29 N., R. 30 E., sec. 5daa	999	1,500	1,000	––	888.7	––	900.7	884.9
T. 29 N., R. 30 E., sec. 14cdd	1,033	1,300	400	––	956.6June	953.8	979.4	969.5
T. 29 N., R. 30 E., sec. 14cdd	1,033	1,300	400	––	[c]923.0July	––	––	––
T. 29 N., R. 30 E., sec. 14dad	1,015	405	42	––	968.4June	––	988.3	––
T. 29 N., R. 30 E., sec. 14dad	1,015	405	42	––	975.7July	––	––	––
T. 29 N., R. 32 E., sec. 1abb	935	1,225	550	––	740.9	727.3	744.1	––
T. 29 N., R. 33 E., sec. 4abb	870	1,200	––	––	715.0	––	712.3	708.9
T. 29 N., R. 33 E., sec. 27cdc	940	962	840	––	840.3	––	846.1	839.3
T. 29 N., R. 34 E., sec. 2dcc	895	925	480	––	696.0	––	703.2	700.2
T. 30 N., R. 29 E., sec. 27cdc	1,090	1,246	80	––	1,016.9	1,017.3	1,038.4	1,020.6

[a]Water level used on 1982 Cambrian-Ordovician potentiometric map.
[b]Well recently pumped.
[c]Pumping measurement.

TABLE 11 (cont.)

Location	Altitude of land surface (ft above sea level)	Well depth (ft)	Casing depth (ft)	Spring 1981	Summer 1981	Fall 1981	Summer 1982	Fall 1982
			Jasper County (cont.)					
T. 30 N., R. 29 E., sec. 35ccc	1,084	1,220	80	——	957.4	963.6	986.7	967.5
T. 30 N., R. 30 E., sec. 27ddd	1,005	870	400	——	877.5	874.4	890.0	890.6
T. 30 N., R. 31 E., sec. 20cab	935	1,150	450	——	700.5	694.3	706.3	696.5
T. 30 N., R. 31 E., sec. 24ccb	945	1,500	453	——	813.0	——	[a]833.8	——
T. 30 N., R. 32 E., sec. 17bca	935	1,095	400	——	691.7	685.2	696.0	686.3
T. 30 N., R. 32 E., sec. 31ddc	908	1,001	400	——	704.7	702.4	708.2	699.4
			St. Clair County					
T. 36 N., R. 24 E., sec. 7ccb	856	190	35	——	——	811.2	812.2	——
T. 36 N., R. 24 E., sec. 7cdc	934	570	495	——	——	——	[b]808.5	——
T. 36 N., R. 26 E., sec. 11cdd	815	240	184	——	——	721.3	734.3	728.6
T. 36 N., R. 26 E., sec. 16bbc	775	120	54	——	——	729.7	[c]727.1	731.2
T. 37 N., R. 24 E., sec. 13ccd	972	500	270	——	——	818.8	828.4	——
T. 37 N., R. 24 E., sec. 21bad	862	250	21	——	——	795.1	787.4	——
T. 37 N., R. 25 E., sec. 18aca	788	215	38	——	——	724.1	728.7	——
T. 37 N., R. 26 E., sec. 7cbc	830	390	125	——	——	720.6	723.6	720.2
T. 37 N., R. 26 E., sec. 26dbd	831	205	30	——	——	740.2	746.0	745.7
T. 37 N., R. 26 E., sec. 34ddb	821	210	30	——	——	734.1	——	735.1
T. 37 N., R. 27 E., sec. 4bab	808	124	44	——	——	730.1	732.0	——
T. 37 N., R. 27 E., sec. 10aaa	863	210	120	——	——	716.2	——	717.1
T. 37 N., R. 27 E., sec. 22cbb	802	175	100	——	——	729.9	——	731.7
T. 37 N., R. 27 E., sec. 28bda	782	150	62	——	712.9	——	726.3	722.2
T. 37 N., R. 28 E., sec. 3caa	751	100	24	——	——	716.3	742.3	718.9
T. 37 N., R. 28 E., sec. 14dcd	758	175	39	——	——	719.5	——	724.0
T. 37 N., R. 28 E., sec. 21aad	762	155	20	——	726.7	——	729.7	722.6
T. 38 N., R. 24 E., sec. 2dda	964	300	62	——	764.7	——	771.8	——
T. 38 N., R. 24 E., sec. 15aad	910	270	120	——	750.3	——	770.0	——
T. 38 N., R. 24 E., sec. 15cbc	800	315	14	——	736.2	——	749.9	——
T. 38 N., R. 24 E., sec. 27acc	790	275	22	——	——	785.0	791.5	——
T. 38 N., R. 25 E., sec. 2bdd	822	852	252	——	——	——	696.2	——
T. 38 N., R. 26 E., sec. 29cba	870	200	85	——	——	——	729.2	721.5
T. 38 N., R. 27 E., sec. 15bbb	818	195	87	——	——	718.5	729.4	717.1
T. 38 N., R. 27 E., sec. 27cdc	789	120	35	——	——	726.1	——	766.8
T. 38 N., R. 28 E., sec. 5ddd	804	280	260	——	——	715.1	718.3	——
T. 38 N., R. 28 E., sec. 21ada	812	125	37	——	——	772.0	779.4	——
T. 39 N., R. 24 E., sec. 6acb	854	290	45	——	726.6	——	732.0	——
T. 39 N., R. 24 E., sec. 19ddc	931	415	155	——	788.5	——	796.4	——
T. 39 N., R. 24 E., sec. 27ddb	931	420	349	——	725.4	——	[b]739.4	——
T. 39 N., R. 24 E., sec. 28aac	910	325	63	——	716.8	——	725.5	——
T. 39 N., R. 24 E., sec. 34bbb	933	650	327	——	708.5	——	714.3	——
T. 39 N., R. 25 E., sec. 5abb	805	——	——	——	742.0	——	746.7	——
T. 39 N., R. 25 E., sec. 8ccd	880	340	82	——	788.7	——	722.4	——
T. 39 N., R. 25 E., sec. 32bbb	862	500	154	——	838.9	——	840.3	——

[a]Water level used on 1982 Cambrian-Ordovician potentiometric map.
[b]Well recently pumped.
[c]Pumping measurement.

TABLE 11 (cont.)

Location	Altitude of land surface (ft above sea level)	Well depth (ft)	Casing depth (ft)	Spring 1981	Summer 1981	Fall 1981	Summer 1982	Fall 1982
			St. Clair County (cont.)					
T. 39 N., R. 26 E., sec. 13dc––	872	635	313	––	––	––	693.3	705.3
T. 39 N., R. 26 E., sec. 13dca	871	625	250	––	––	––	703.5	[c]549.2
T. 39 N., R. 26 E., sec. 26dab	873	305	138	––	719.4	––	––	720.1
T. 39 N., R. 27 E., sec. 5cca	803	220	42	––	––	731.7	735.8	––
T. 39 N., R. 27 E., sec. 15dbc	845	300	188	––	721.0	––	720.3	716.8
T. 39 N., R. 27 E., sec. 35dca	870	260	178	––	730.4	––	733.9	––
T. 39 N., R. 28 E., sec. 22ccb	831	215	22	––	––	720.2	[a]722.8	––
T. 39 N., R. 28 E., sec. 26cdd	795	385	385	––	––	718.0	[a]721.1	––

[a]Water level used on 1982 Cambrian-Ordovician potentiometric map.
[b]Well recently pumped.
[c]Pumping measurement.

INTERPRETATION OF U.S. SALINITY LABORATORY (1954) CHART

"Low salinity water (C1) can be used for irrigation with most crops on most soils with little likelihood that soil salinity will develop. Some leaching is required, but this occurs under normal irrigation practices, except in soils of extremely low permeability.

"Medium salinity water (C2) can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most cases without special practices for salinity control.

"High salinity water (C3) cannot be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected.

"Very high salinity water (C4) is not suitable for irrigation under ordinary conditions, but may be used occasionally under special circumstances. The soils must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching, and very salt-tolerant crops should be selected.

"The classification of irrigation waters with respect to SAR is based primarily on the effects of exchangeable sodium on the physical conditions of the soil. Sodium-sensitive plants may, however, suffer injury as a result of sodium accumulation in plant tissues when exchangeable sodium values are lower than those effective in causing deterioration of the physical condition of the soil.

"Low sodium water (S1) can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium. However, sodium-sensitive crops, such as stone-fruit trees and avocados may accumulate injurious concentrations of sodium.

"Medium sodium water (S2) will present an appreciable sodium hazard in fine-textured soils having high cation-exchange capacity, especially under low leaching conditions, unless gypsum is present in the soil. The water may be used on coarse-textured or organic soils with good permeability.

"High sodium water (S3) may produce harmful levels of exchangeable sodium in most soils and will require special soil management, good drainage, high leaching, and organic matter additions. Gypsiferous soils may not develop harmful levels of exchangeable sodiums from such waters. Chemical amendments may be required for replacement of exchangeable sodium, except that amendments may not be feasible with waters of very high salinity.

"Very high sodium water (S4) is generally unsatisfactory for irrigation purposes except at low and perhaps medium salinity, where the solution of calcium from the soil or use of gypsum or other amendments may make the use of these waters feasible."

GLOSSARY

Aquifer - A formation, group of formations, or a part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells.

Aquifer Test - Method in which a well is pumped at a constant rate and water-level measurements are made from it and, where possible, from nearby observation wells penetrating the same aquifer. Values of drawdown or recovery, versus time are used in mathematical formulas to derive aquifer characteristics, such as transmissivity and storage coefficients.

Confined Aquifer - An aquifer in which water is under sufficient pressure to rise in a well above the level of the water-yielding bed. The pressure is occasionally great enough to cause water levels to rise above land surface, resulting in a flowing, or artesian, well.

Confining Bed - A body of relatively impermeable material, overlying an aquifer, that restricts vertical water movement and causes hydraulic pressure in the aquifer.

Evapotranspiration - The movement of water into the atmosphere by the combined processes of direct evaporation and transpiration by plants.

Permeability - A measure of the relative ease with which a porous medium can transmit a liquid under a potential gradient.

Potentiometric Surface - An imaginary surface that represents groundwater static head. As related to an aquifer, it is defined by the levels to which water will rise in a tightly cased well.

Recharge - The addition of water to the zone of saturation. Infiltration of precipitation is a form of natural recharge.

Secondary Permeability - Increased capacity of rocks to transmit water, due to such phenomena as bedding planes, rock fracturing, or solutioning in the rock.

Specific Capacity - The rate of discharge of water from a well, divided by the drawdown of water level in it. If a well yields 500 gpm, with a drawdown of 25 ft, its specific capacity is 500/25 or 20 gpm/ft.

Specific Conductance - A measure of the capacity of water to conduct a current of electricity, expressed in micromhos per centimeter. Specific conductance varies with the amount of dissolved mineral constituents, their degree of ionization, and water temperature. It is useful in indicating the approximate concentration of mineral matter in water.

Storage Coefficient - The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer, per unit change in hydraulic head.

Transmissivity - The rate at which an aquifer can transmit water, expressed as feet squared per day. Transmissivity is the volume of water per day that can move through a 1-ft-wide vertical aquifer section extending the full saturated thickness under a hydraulic gradient of 1 ft/ft at the prevailing temperature of the water.

Unconformity - A surface of erosion or nondeposition that separates younger from older rocks.

Water Table - That surface in an unconfined groundwater body at which the water pressure is atmospheric. It is defined by the levels at which water stands in wells that penetrate the water body just far enough to hold standing water.

April 1985

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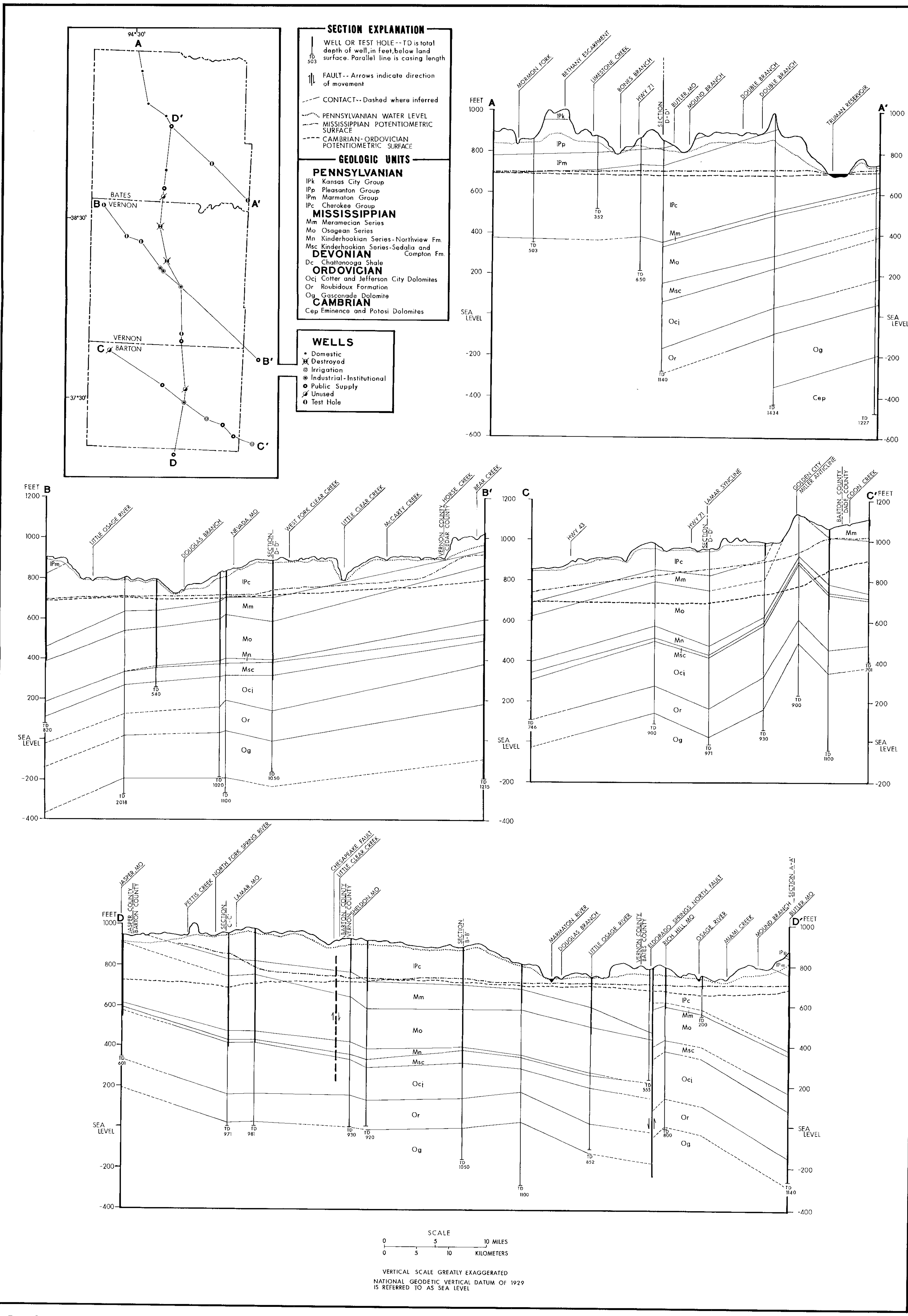

GEOHYDROLOGIC SECTIONS IN BARTON, VERNON, AND BATES COUNTIES, MISSOURI.